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Education for science

Of the many changes in science which have marked the past few decades, none is more arresting than the vast acceleration in the rate at which new facts relating to natural phenomena have been accumulated. These facts are, of course, the essential raw material of science, and their recent profusion is a healthy sign. At the same time, their intrinsic importance may easily be overestimated. The advancement of science depends not only on the discovery of new facts but upon their value for the establishment of new principles or the confirmation of accepted ones. A few simple experiments, for example, were sufficient to confirm Dalton's faith in his atomic theory, but only the genius of a Dalton could have perceived the full implication of the facts or have shown that a great body of existing knowledge could now be summarized in a single generalization. The indispensability of facts, which must always make their discovery one of the main tasks of scientific research, is matched by the indispensability of those abstract qualities of insight, reasoning, and critical judgment necessary to their full appreciation.

In laboratory facilities and in scientific training the scientist of today is far better equipped than his predecessors of even two or three generations ago. It is nevertheless questionable whether the modern scientist has in general gained that broader outlook for which the tremendously increased importance of science so clearly calls. No one would wish to deny that, in the British Empire and Commonwealth and throughout the rest of the civilized world, there are many scientists of outstanding merit, whose brilliance—both within science itself and in wider fields of human affairs—is as great as that of the leading figures of any age. Their number is, however, relatively small in proportion to the tens of thousands for whom science is little more than a means of making a livelihood, and who—if they reflect upon the matter at all—are at best inclined to regard the significance of science to mankind as wholly utilitarian. Such a state of affairs perhaps becomes inevitable in any professional occupation when the ranks are swollen too far, but the attitude and general cultural background of the present-day scientist contrast noticeably with those of the typical scientist of earlier centuries. It was no mere coincidence that the leaders of the golden age of science which began with the *Principia* and ended with the discovery of radioactivity were men of wide culture (in the best sense of that unfortunate word), not only trained to sift truth from error and to fit facts into the pattern of natural laws, but endowed with scholarship and not unfamiliar with the arts. A return by modern men of science to the more liberal training and outlook of former days might well be to their advantage, and the advantage of their work.

In this issue we publish an article by Professor T. A. Stephenson which admirably exemplifies one direction in which the arts may lend assistance to science. The author's combination of scientific knowledge and artistic ability enables him to convey an impression of coral reefs at once accurate and vivid, intellectually satisfying and aesthetically compelling. Such an impression could not be given by any mere written account, however detailed. A statement of the species and varieties, their distribution, their colour, and so on would doubtless be sufficient for many purposes, but no account of natural objects or phenomena that ignores aesthetic values can claim to be comprehensive. Beauty is a stimulus to thought and imagination; its critical appreciation is part of the liberal education with which scientists should certainly be equipped but which they far too frequently lack.

There are admittedly many difficulties in providing scientists with such a desirably broader

education. The scientist of independent means, able to pursue his studies for their own sake, is today a rarity and has given place to the professional scientist. The very expansion of science makes increasingly difficult the acquisition of those cultural attainments which were so closely linked with its early success, and the professional scientist usually feels it necessary to devote all, or practically all, his energy and attention to his scientific work. There is also an ever-increasing tendency to specialization, and already the subdivision of science into the familiar branches of physics, chemistry, biology, geology, and so forth is proving inadequate. Studies of much more limited scope, such as biochemistry or nuclear physics or mycology, provide ample fields of research for even the most accomplished investigators. The specialist has been defined as a man who knows more and more about less and less, and it is indisputable that before the young research worker can venture out on his own he must acquire, or at least know where to find, a very great amount of knowledge of work already done in his chosen field. In most instances, economic reasons make it essential that this preliminary discipline be completed as quickly as possible; it is therefore almost always impracticable for the science student to devote a year, or even so much as a single term, to studies other than those of immediate professional use.

As the time available for cultural learning is thus so severely and perhaps inevitably limited, it is highly desirable that the science student should be actively encouraged to make the best possible use of what time he has. The mere provision of opportunity is not sufficient: there should be greater effort on the part of the authorities to ensure that it is not neglected.

In certain universities it is, or used to be until quite recently, the custom for arts students to read at least one science subject. The scheme is an excellent one, and *mutatis mutandis* might well be adopted for science students. The trouble with university science is that it turns out men qualified to follow a scientific career but rarely fitted for anything else. The man who reads classics or history or philosophy is not similarly limited, and in fact does not usually become a professional classicist, historian, or philosopher. Would not the ideal university science education leave its graduates an equal freedom of choice? And would not this in the long run prove beneficial to science, to the individual, and to the whole community?

It should be remembered that the intensive specialization of university courses affects not only the subsequent but also the precedent career of the scientist, for the schools feeding the universities have in practice if not in theory to meet the university demands as to the standard of knowledge required for matriculation. In consequence, the boy or girl intending to read science at the university has to begin to specialize two or three years before leaving school, and the narrowness of outlook is likely to have become fixed even earlier than university days.

There is obviously a problem here, and no simple solution presents itself. Perhaps several partial solutions are more promising things to aim at than a single comprehensive one. For example, far more use could be made of the cultural value of science itself by including work on the history of science or the philosophy of science, or both, as an integral part of the curriculum for a degree. The history of science is worth pursuing for its own sake and can in addition prove of the utmost practical value. It is significant that the majority of those scientists who have made fundamental contributions to scientific knowledge have been assiduous students of the history of science. Yet comparatively few universities give any official time at all to the history or philosophy of science.

In a scientific journal it is not necessary to expatiate on the desirability of the steady advancement of science. It is, however, necessary to take stock of the position from time to time, and at the present moment we may usefully ask ourselves whether the prevailing tendency to closer and closer specialization possesses sufficient merits to outweigh its very apparent demerits. The progress of science has depended upon the existence of men able to think in the broadest terms and to perceive unity in diversity. Such men cannot be nurtured on science alone; much less can they prosper in a parochial area of science.

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Migration of vertebrate animals

J. GRAY

Although the phenomenon of migration has long excited curiosity, it is only in comparatively recent years that it has received the detailed investigation it deserves. Painstaking research has established the main facts relating to the migrations of many vertebrate types, but the interpretation of the facts there collected, in regard both to the reasons for migration and to the means by which the long journeys involved are successfully made and retraced, is still uncertain. In this article Professor Gray summarizes the tendency of current opinion.

Among vertebrate animals, long-ranged cyclical movements are particularly characteristic of aquatic and aerial forms—fish, birds, seals, whales, and some bats. In every case they raise two fundamental problems: (i) What determines the time, direction, and extent of an outward journey towards what is, almost invariably, a breeding site? and (ii) Why and how does the animal or its offspring forsake its breeding site and return to its original starting-point? The following survey of the migratory activity of certain vertebrate types may serve to indicate the drift of current opinion.

Among fish, classical examples of long-range migration are provided by the eel and salmon; less spectacular but none the less significant movements are, however, carried out by such forms as the cod and many other fish which form the basis of important industries. Cod (*Gadus morrhua*) are distributed in the sea in large shoals, each of which behaves as a more or less independent entity. The main feeding ground of one of the most important of these aggregations lies in the relatively shallow cold waters in the region of Spitsbergen, Bear Island, and the Barents Sea: here the young fish spend their early years growing rapidly on abundant plankton. After eight years they become sexually mature and migrate to the west coast of Norway to form dense spawning shoals in the neighbourhood of the Lofoten Islands. There the eggs develop, and in due course the resultant larvae drift passively northwards in the prevailing currents, the spent fish moving more slowly in the same direction. Eventually, both parents and young fish return to the feeding grounds. The cold northern waters are essentially feeding areas rich in plankton, while the warmer waters of the spawning ground permit the eggs to develop at a rate which is presumably sufficient to enable the young fish to feed by the time they have been carried passively to a suitable 'nursery' feeding ground. As has been pointed out by Dr E. S. Russell, this and other instances of fish migration conform to the rule that the active mature fish swim against the prevailing current before depositing their eggs, while the eggs and larvae are carried passively by the current towards an appropriate nursery. It must be borne in mind, however, that a constant current cannot provide a fish with any direct clue concerning its position relative to the ground; it is only when a fish is receiving visual or other types of stimulation from a fixed object (e.g. by swimming near the sea floor) that it can control its movements relative to the earth. On the other hand, a mass of water having specific temperature or salinity gradients might well provide an effective means of navigation, since fish can detect such gradients with an extremely fine degree of precision.

A similar passive drift of fish larvae towards the feeding grounds is illustrated by the eastward movement, across the Atlantic, of the larvae of the European eel; we can, however, only speculate how far the upstream migration of the elvers into fresh water depends on hydrographical factors. Similarly, we can only conjecture how far the westward migration of the adult eels, when once these have reached the sea, is essentially a steady progression into deeper and deeper water, or how far it is dependent on the passive action of oceanic currents. It is, however, in the case of the salmon that the migration of fish seems to reach its most perplexing form, for within recent years the general trend of the evidence is towards the belief that the adult fish shows a marked tendency to return to the stream in which it has previously spent its early years as a smolt. The evidence in support of this remarkable conclusion is largely derived from observations on the various species of the Pacific Salmon (*Onchorhynchus*) in the United States and Canada. In 1929 Rich and Holmes showed that the adult King Salmon

(*O. tschawytcha*) which enter the main Columbia River do so in two main runs, one in spring and the other in autumn. Those which enter in spring pass upstream for nearly a hundred miles and then turn southward into the Willamette River; those which enter in the autumn move continuously east into the upper reaches of the Columbia. By marking large numbers of smolts before their descent to the sea, two important conclusions were reached. (i) Fish which have developed in the Willamette and Columbia, respectively, return to their original rivers. A very surprisingly large percentage of the recaptured fish are recovered from very small tributary streams from which some of the total stock of marked smolts had originally been derived. (ii) Fish which have developed from eggs derived from Willamette fish, but which have been hatched and reared in the upper Columbia, return as adults to the latter river, although at the time of the year characteristic of the run into the Willamette. Comparable 'homing' phenomena were observed by Davidson in the Pink Salmon (*O. gorbuscha*) and by Foerster in *O. nerka*. In the latter case, smolts were marked and replaced into the Cultus River, a small tributary of the Fraser: out of a total of 967 recaptured adult fish, 83 per cent. were taken in the Cultus river, the remaining 17 per cent. in the fishery grounds at sea, and none from any other spawning ground. These results suggest that when in fresh water the young fish have a very definite topographical sense, based conceivably on patterns of water temperature, oxygenation, or chemical composition; they suggest too that the fish 'remember' these patterns and associate them with the proximity of a specific spawning ground. These conclusions are sufficiently important to warrant the exercise of considerable caution before regarding them as fully established principles of fish behaviour. It must be borne in mind that we have, as yet, very little precise knowledge concerning the extent or direction of the movements carried out in the sea by fish which have returned to their original spawning ground. So far, our knowledge appears to be restricted to data derived from two individual fish (*O. gorbuscha*) which were marked as fry by Pritchard at Morrison Creek, Vancouver Island. One of these fish was caught on 19th August, 1943, at Deep Water Bay, Johnstone Strait (forty-five miles north of Morrison Creek) and retaken at Morrison Creek on 6th October; the other fish was caught on 30th August, 1943, off Lopez Island, Puget Sound (115 miles south of Morrison Creek) and retaken at Morrison Creek on 6th October. The evidence certainly suggests that this species of *Onchorhynchus* travels for relatively long distances beyond the mouths of its rivers of origin, and has, during its return journey, opportunities of entering spawning streams other than its own. On the other hand, until these two points have been thoroughly investigated, our general picture of 'homing' ability in fish must remain liable to revision. The need for further inquiry seems emphasized by what is known of the movements of the Atlantic Salmon (*Salmo salar*) on the eastern seaboard of Canada. Huntsman concluded that those smolts which return to their river of origin do not proceed to sea for distances far beyond the zone over which the outflow of their parent river can exert a physical or chemical influence, and consequently an inshore migration automatically brings them to the vicinity of their own river; fish which migrate for long distances have not, as yet, been proved to return. Again, the accuracy of the 'homing' migration in *Onchorhynchus* appears to vary with the number of alternative spawning sites available to the returning fish; if only one site provides the physical requirements of an effective spawning ground the concept of 'memory' seems no longer necessary, since the site could be found by random exploration. In contradistinction to the conclusion reached by Rich and Holmes for the Pacific Salmon, White and Huntsman concluded that the 'autumn' or 'spring' running habit of the Atlantic Salmon is determined by the nature of the stream in which the smolts develop and not on the genetical constitution of the fish. In the case of British salmon, there is some circumstantial evidence in favour of 'homing' activity, and it is to be hoped that much-needed further investigations will not be long delayed. Such investigations should not be restricted to a detailed study of the physiology and movement of the fish, but should include a very careful hydrographical survey of the waters through which they migrate.

Migratory activity at the breeding season is common among amphibia, and similar movements occur among amphibious reptiles, but in no case do these migrations appear to approximate in magnitude to those of fish or birds. Wide as is the evolutionary gap between the last two classes of vertebrates, the main features of their migrations seem curiously similar: in all cases the movements are keyed into cycles of reproductive or nutritional activity. The migratory cycle of birds, however, is more closely linked with

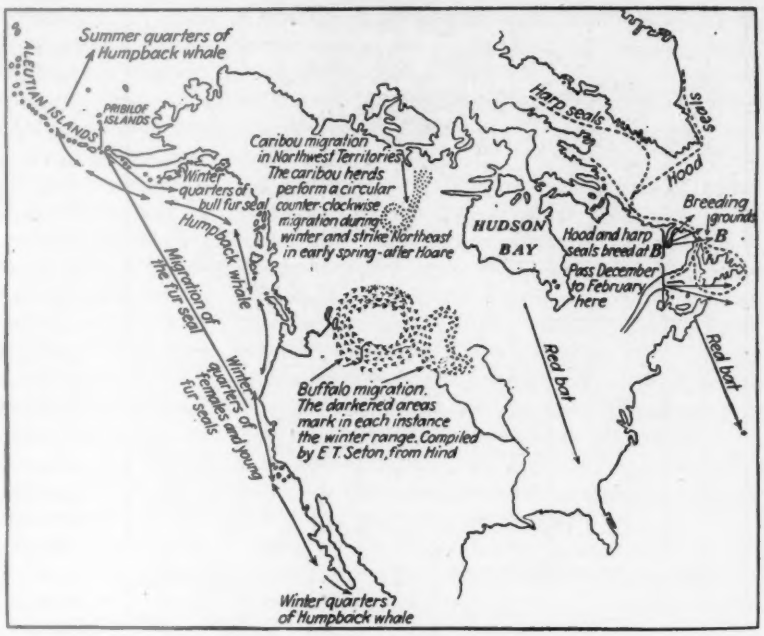
Summer quarters of Humpback whale
ALEUTIAN ISLANDS
PRIBILOF ISLANDS
Caribou migration in Northwest Territories. The caribou herds perform a circular counter-clockwise migration during winter and strike Northeast in early spring-after Hoare
Winter quarters of bull fur seal
Humpback whale
Migration of the fur seal
Winter quarters of females and young fur seals
Harp seals
Hood
Breeding grounds B
HUDSON BAY
Hood and harp seals breed at B
Pass December to February here
Reed bat
Reed bat
Buffalo migration. The darkened areas mark in each instance the winter range. Compiled by E T Seton, from Hind
Winter quarters of Humpback whale

FIGURE 1 – The Migration Routes of Several North American Species. *Whales of several species summer in the Arctic seas and spend the winter months off the coast of lower California. The winter quarters of migratory bats are not well known, but they have been taken on ships far at sea and on Bermuda.*

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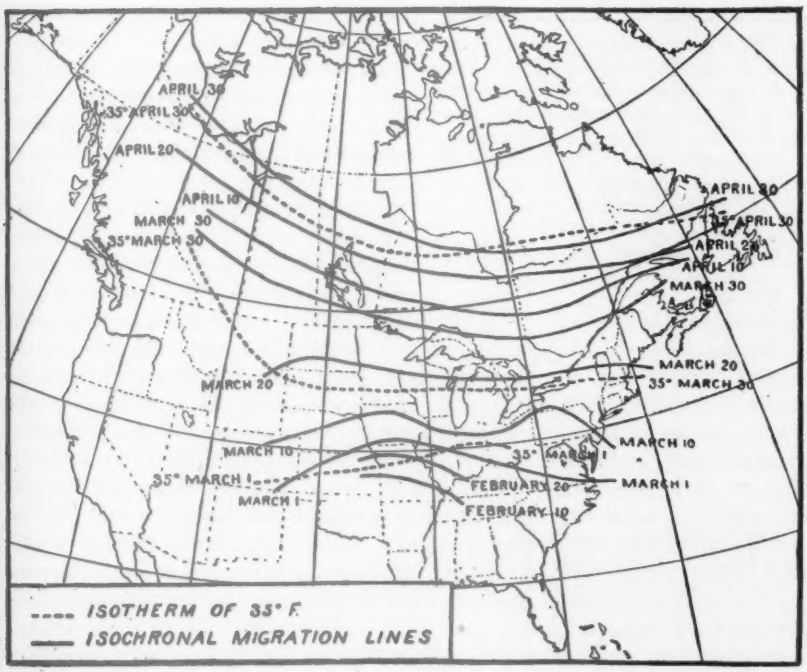

FIGURE 2 – Migration of the Canada Goose. *The northward movement keeps pace with the advance of spring, in this case the advance of the isotherm of 35° F. agreeing with that of the birds.*

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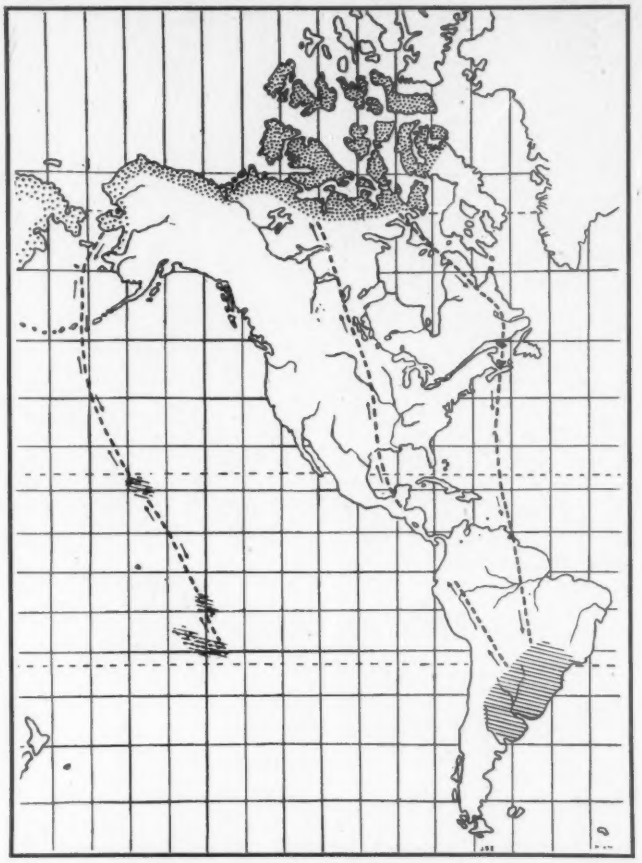
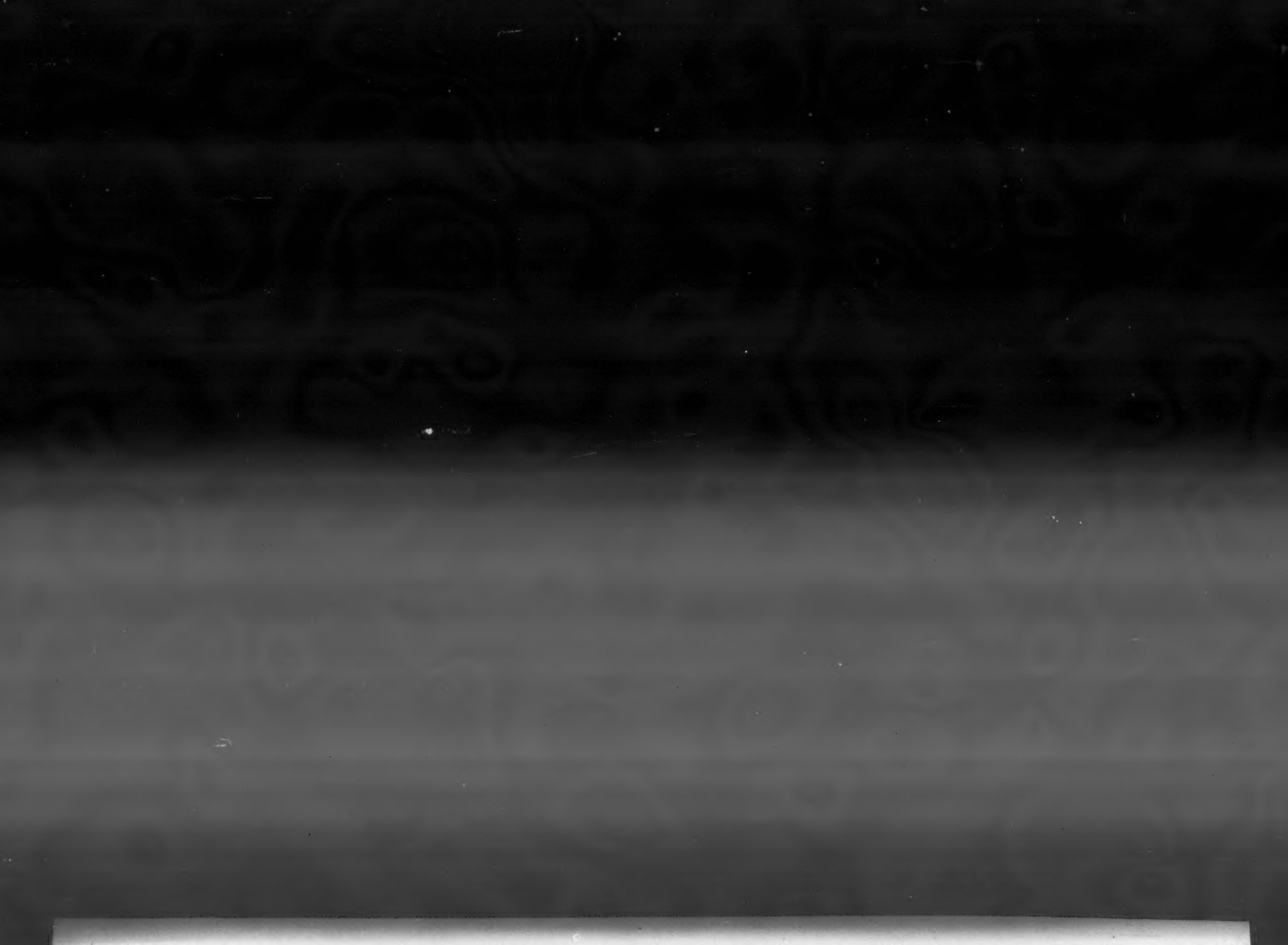


FIGURE 3 – Distribution and Migration of the Golden Plover, Charadrius dominicus. *Adults of the eastern form* (Ch. dominicus) *migrate across north-eastern Canada and then by a non-stop flight reach South America. In spring they return by way of the Mississippi Valley. Their entire route is therefore in the form of a great ellipse with a major axis of* 8,000 *miles and a minor axis of about* 2,000 *miles. The Pacific golden plovers* (Ch. fulvus), *which breed in Alaska, apparently make a non-stop flight across the ocean to Hawaii, the Marquesas Islands, and the Low Archipelago, returning in spring over the same route.*

(Reproduced by courtesy of the United States Department of Agriculture.)

annual cycles of seasonal change than is that of fish. Birds resident in the tropics may exhibit definite migratory phenomena in response to local conditions, but it is essentially in those which extend their breeding range to temperate or arctic zones that the most striking and extensive patterns of migration are found to occur. It is therefore reasonable to assume that the migratory habit has been impressed upon the behaviour of the birds by climatic factors operating either during the past history of the species or during the lifetime of existing individuals. It must be frankly admitted, however, that the available facts do not readily fit into any simple or convincing picture. In broad outline the migratory movement in the northern hemisphere is towards the north in spring and to the south in autumn. In this way the bird avoids the rigours of the northern winter while enjoying the long hours of the northern summer when rearing its young. In each species, the northern movement occurs within reasonably constant dates each year, and it has long been suspected that either an increasing period of daylight or an increase in mean daily or nightly temperature may be the operative factor. Rowan showed that artificial variation in the period of illumination of juncos and crows had a profound effect on the rate of maturation of the ovary and testis, and at the same time affected migratory activity. The state of the gonads as controlled by light cannot, however, account for the northern migration of birds which winter within the tropics, or of young birds (e.g. those of the gannet) which migrate northwards before they are sexually mature. Further it is difficult to see how light can be an operative factor in cases where the spring migration is essentially from west to east, as appears to be the case with starlings nesting in northern Germany. Kendeigh's observations on the eastern house-wren (*Troglodytes aedon aedon*) suggest that migration is regulated more by temperature than by light; in spring and early summer the birds tend to move away from regions of unduly high daily temperature, but eventually the northward movement is checked at latitudes where the high rate of metabolism required to protect them against low night temperatures can no longer be fully sustained by the food which can be consumed during the day. This view seems to be supported by the observations that the rate of northward migration follows reasonably closely that of an isothermal line, which varies for different species. Nevertheless it is difficult to see how such changes in diurnal temperatures can operate on birds which winter within or south of the tropics.

Just as it is difficult to say why a migrating bird



leaves its winter quarters, so it is difficult to demonstrate the factor which urges it to leave its nesting area. In extreme cases the decreasing period of diurnal feeding may well operate with decreasing nightly temperature to produce conditions from which the birds must either migrate or die, but the facts do not suggest that such things are always the primary or dominating factors. Even within the range of a single species, the period of migration away from the nesting site for some individuals overlaps the period of reverse migration in other individuals. Similarly, many cases are known where only part of a population exhibits migratory movements: some individuals remain resident, while others migrate. The most satisfying picture of a typical migratory cycle is probably that provided by Thomson, who suggests that it is essentially an expression of an inherent genetical rhythm of metabolic change or behaviour-pattern whose onset can be accelerated or delayed by environmental factors. This conception accounts for the migratory activity of birds wintering in the tropics but implies the inheritance of a mechanism which responds to an extraneous environmental factor in such a way as to limit the bird's movement to a particular direction. Valuable information concerning the nature of this factor might be forthcoming from a careful study of the extent to which climatic factors form definite gradients within the range of the bird's daily non-migrational movements, and of the extent to which the detection of these gradients falls within the limits of the bird's sensory perception at various phases of its reproductive cycle. As will be shown later, however, the power of a bird to return to its home after passive transportation is not always restricted to the direction characteristic of its seasonal migration. It must also be remembered that closely related species of birds may display very different levels of migratory activity.

The existence of an extraneous factor which limits the bird's movement to a particular direction represents one of the most interesting but perplexing of all biological phenomena. How does the bird control the direction of its migratory flight, and, above all, how does it return many months later to its starting-point after a journey of many hundreds or thousands of miles? These questions must remain unanswered until we possess more accurate and complete knowledge concerning the direction of flight during the whole of the migratory cycle. Roughly speaking, there are two main types of theory: (i) Those which postulate the existense of sensory clues whereby the bird navigates towards a specific goal. (ii) Those which regard the bird's return as the result of more or less systematic exploration unaided by sensory guides. In the case of relatively short-ranged movements there can be little doubt that visual clues play an important if not exclusive role. During its outward flight the bird almost certainly orientates its movement by reference to conspicuous features on the ground, seeking meanwhile for a suitable nesting site; during the return flight to its winter home the bird 'remembers' these landmarks and navigates accordingly.

Most of the older charts of migratory routes support the view that migrant birds follow a definite 'flight line' marked out by distinctive features of the landscape—coastlines, river valleys,

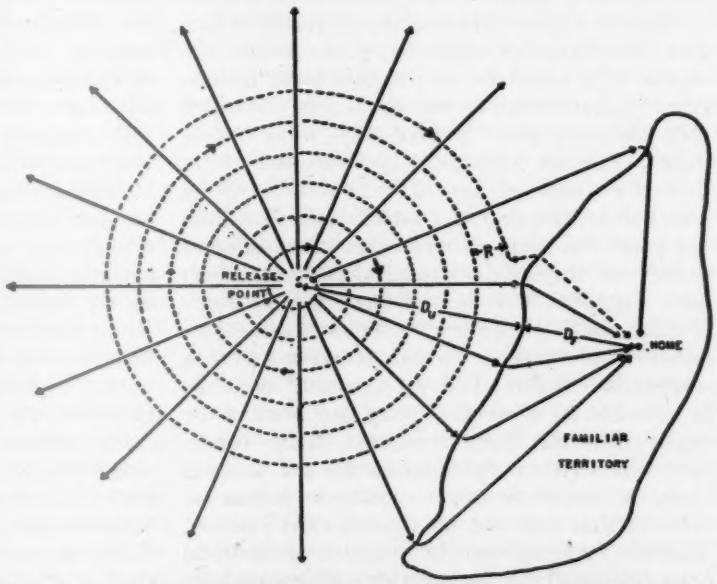


FIGURE 4 – *Hypothetical flight paths of birds homing by means of radial scattering (solid lines) and spiral exploration (dotted lines). In this diagrammatic instance five out of sixteen birds reached home by means of radial scattering, flying courses* 1·03, 1·04, 1·18, 1·67, *and* 1·7 *times the straight-line distance* DF + DU. *The bird homing by spiral exploration would have flown approximately* 13·3 *times the straight-line distance.* (*Reproduced by courtesy of the* Quarterly Review of Biology.)

short sea routes, and mountain ranges. It is, however, obvious that visual methods of navigation cannot account for certain well-established facts. Firstly, the range from which some species can home successfully is far beyond that over which they can be reasonably expected to have had previous visual experience. Starlings have returned from Berlin to almost all parts of Germany after forced journeys varying from twenty-five to nearly four hundred miles; ducks bred in Louisiana have returned from the Pacific and Atlantic seaboards of the United States; shearwaters native to South Wales have returned from Venice. Secondly, many of the most spectacular migrations involve long and continuous flights over the sea far away from land; the Bronze Cuckoo (*Calcites lucidus*) winters in the Solomon Islands, and its flight to its breeding area in New Zealand involves a transoceanic flight of at least nine hundred miles. Thirdly, the weight of recent evidence tends to support the view that migration often occurs over a broad front, and that the course followed on the homeward journey may differ very considerably from that of the outward journey. According to Moreau, the migration of the White Stork (*Ciconia ciconia*) across Egypt occurs over a front of six hundred miles, and many of the birds must be far outside visual range of such navigational features as the Nile Valley. Many of the difficulties which beset the theory of visual navigation might disappear if it could be shown that birds include celestial phenomena in the visual field by which they orientate their normal day-to-day movements. For this suggestion, however, there is at present no basis of fact. The limitations of the visual sense as a basis for aerial navigation raise the possibility that sensory clues of a different nature are employed. Exner, Meise, and others have suggested that a bird may use its semicircular canals or the proprioceptor organs of its muscles and joints to register deflections from a straight-line flight. The experimental evidence is, however, far from convincing, and none of the experiments has been conducted under conditions which effectively eliminate the use of visual clues; further, the return route is by no means the same as that followed on the outward journey. That birds may navigate by magnetic or electrical clues is exceedingly improbable. There remains the possibility that 'homing' is effected, not by means of definite sensory navigation, but by organized exploration. Theories of this type include the spiral type of flight advocated by Hodge for homing pigeons: a bird is presumed to fly along a spiral path of ever-increasing radius until it inevitably comes in sight of known territory. It is almost inconceivable that such a procedure would enable a bird to return from a point many thousands of miles away from its goal. Less unconvincing, perhaps, is the suggestion of Claparede, whereby a bird is assumed to fly along a straight line, whose direction is determined by chance. On this basis the number of individual birds which would reach their 'goal' would vary inversely with the distance to be flown and directly with the size of the territory previously known to the bird. Griffin has shown that the data available from birds artificially removed from their natural locality conform to this general rule. Unfortunately, there is considerable doubt concerning the extent of territory over which a bird can or does range during the non-migratory phases of its life. At the same time it hardly seems possible that a serious element of chance is involved in the case of an individual migrant returning from many hundreds of miles to the same nesting site for two years in succession, or in the movements of the Golden Plover (*Charadrius fulvus*) between Alaska and Hawaii. It seems strange that we are unable to assess the significance of sensory navigation as opposed to that of non-directional exploration. A decisive test ought to be possible by anaesthetizing birds during the outward journey; unfortunately, all experiments of this type have so far been inconclusive, since they have not been done under conditions which fully eliminate the possibilities of visual navigation or chance discovery.

Among terrestrial mammals seasonal migrations are not uncommon, especially in sub-arctic and sub-tropical regions. In North America elk and caribou migrate in large herds towards definite winter feeding grounds; similarly, in the Orange River district of Africa the springbok migrate at the breeding season to the rich vegetation of the upland regions. It is, however, among aquatic types that the most spectacular instances of mammalian seasonal migration occur. One of the most interesting of these movements is that of the Fur Seal (*Callorhinus alascanus*), in which the females and immature males winter as far south as Southern California while the mature males winter in the Gulf of Alaska or near the Aleutian Islands. At the breeding season the mature males migrate northwards to the Pribilof Islands—small rocky islands north of the Aleutians and two hundred miles from the nearest land. At this small isolated breeding ground the females also foregather after a

journey of three thousand miles, which is said to be effected on a 'true course.' These females are pregnant and give birth to their young within a few days of their arrival; soon after weaning their young they are again impregnated and set out on their southerly migration. Although different in some respects, the general cycle raises the same essential problems as those raised by migratory birds. In both cases the mechanism which controls the direction of the movements is quite obscure, and is likely to remain so until a great deal more is known of the physical properties of the medium through which the movement occurs and of the extent to which the animal's sensory equipment enables it to detect very slight changes in these properties. At the same time it must be remembered that accurate observation of the precise movements of an individual bird or a whale over a considerable period of time is extremely difficult; we have, therefore, to rely on data which are liable to a good deal of statistical error—it is very easy to attribute undue significance to isolated observations. The same difficulties arise in attempting to assess the homing ability of dogs. Popular literature is rich in accounts of dogs returning to their homes after transportation for long distances; we must not forget, however, the frequency of advertisements for lost dogs. In view of its intrinsic interest it is strange to find that very few attempts have been made to approach the problem from a scientific angle. Adequately controlled experiments would be difficult, but by no means impracticable.

In addition to seasonal or reproductive migrations, some mammals exhibit marked 'emigrational' outbursts which occur at relatively irregular intervals. Of these the lemming is the classical example. This small rodent lives in colonies in the barren arctic steppe country of eastern Scandinavia. It normally breeds twice a year and has four or five young in a litter. At somewhat irregular intervals (2–4 years) the population of lemmings is built up to a very high level—possibly owing to increase in fertility. When this occurs, almost the entire population begins to move down the western valleys which radiate downwards from the mountainous plateau. This process goes on progressively until the lemmings enter the sea and are eventually drowned. The facts as recorded by Collett seem to establish five points with tolerable certainty:

(i) The migration is dependent on the existence of an abnormally high level of population density.

(ii) It is not directly due to lack of food or other ecological factors—a limited number of lemmings remain resident in their original haunts, and from these a new population is built up.

(iii) The migration does not increase the permanent zone of distribution of the species.

(iv) The vast majority of emigrants perish.

(v) Migration involves a change in the physiological state of the animal, rendering a shy, timid creature relatively bold, if not pugnacious.

The general picture of the whole phenomenon can be regarded as 'a rather tragic procession of refugees, with all the obsessed behaviour of the unwanted stranger in a populous land, going blindly on to various deaths' (Elton). Closely similar to this remarkable migration are the mass movements of springbok and other game at cycles varying from ten to twenty years. These have been described by Heape and other writers. Vast numbers of animals, forming wide continuous columns, migrate westward for many days on end. Countless numbers die on the way, but eventually the remainder reach the sea, where they too perish. From such great movements there is no return.

Unidirectional migration is not restricted to mammals. Pallas's Sandgrouse (*Syrrhaptes paradoxus*) is normally resident in eastern Europe and central Asia, with rare stragglers in western Europe. In 1863, and still more in 1888, however, large numbers appeared over the whole east coast of Britain and spread over the whole of the British Isles. Comparable but perhaps less spectacular 'invasions' by other species are known. It is just possible that these phenomena may be associated with particular environmental conditions, but it seems more likely that they represent a response on the part of a population which has, for one reason or another, suddenly reached a magnitude far beyond that which can be supported by its normal range of territory. In this respect they appear to be related to the spasmodic migration of locusts, where the migratory habit seems fairly clearly associated with population density and thus with circumstances which appear to be conducive to a gregarious existence.

A review of the available evidence makes it fairly clear that each of the main problems raised by migrating animals still remains unsolved; at the same time there seems no reason to believe that they are insoluble.

The Imperial College of Science and Technology

H. J. T. ELLINGHAM

The Imperial College of Science and Technology resulted from the fusion of several previously existing institutions, of which the oldest was founded just over a century ago. It is perhaps to this multiple origin that the College owes the cosmopolitan outlook which has done so much to establish its present world-wide reputation. In this authoritative article Dr Ellingham gives a clear account of the rather involved early history of the College, and of the many eminent scientists who have been associated with it as graduates or teachers.

The Imperial College of Science and Technology, constituted by Royal Charter in 1907, is a federation of three institutions that had previously become established at South Kensington. The youngest of these, the City and Guilds College, was founded there in 1884 as the Central Institution of the City and Guilds of London Institute. The other two, the Royal School of Mines and the Royal College of Science, have longer and more complex histories extending back to a common ancestor, the 'Government School of Mines and of Science applied to the Arts,' which was established in the Museum of Practical Geology, Jermyn Street, in 1851. The Chemistry Department of the Royal College of Science, however, originated in a still earlier foundation, the 'College of Chemistry,' which was opened in George Street, Hanover Square, in October 1845.

In the second quarter of the last century there occurred a gradual awakening to the importance of science for the more effective utilization of the natural resources of the country. In 1834 Henry Thomas de la Beche persuaded the Government to establish the Geological Survey of the British Isles, and, as the first director of this new department, he was active in building up a Museum of Economic Geology in Craig's Court, adjoining Scotland Yard, where a limited number of pupils was received for instruction in mineralogy, metallurgy, and analytical chemistry. In 1842 a group of private persons put forward a scheme for the foundation of a school of practical chemistry which they proposed to name after Sir Humphry Davy. An application to the Royal Institution for accommodation for the proposed school was rejected on the ground of lack of space, but the enthusiasm of the promoters of the scheme, among whom was de la Beche, was not damped. At a public meeting held in St. Martin's Place on 29th July, 1845, definite form was given to the proposed College of Chemistry and a council was elected of which Prince Albert consented to be president. Through the personal intervention of the Prince, August Wilhelm von Hofmann, then *Privatdozent* at Bonn, was enabled to accept the professorship.

Temporary laboratories were fitted up in a house in George Street, and the College—the first organized school of practical chemistry in England—was opened to students in October 1845. In December, Queen Victoria permitted the new institution to be named the 'Royal College of Chemistry,' and in the following year permanent quarters were obtained in a specially erected building at 299 Oxford Street. The available accommodation—eventually for about fifty students—was soon taken up by 'men of all ages, of all ranks, and of a variety of professions—gentlemen following chemistry as a profession or as an object of scientific taste, chemists and druggists, medical students and medical men in practice, officers in the Army, clergymen, agriculturists, manufacturers in almost all branches of the chemical arts.' Among those who passed through Hofmann's hands were many who subsequently exercised a dominant influence on the development of science and industry. The first five years of the College produced Sir Frederick Abel, Sir William Crookes, Sir Edward Frankland, Warren de la Rue, William Odling, Frederick Field (who developed copper-smelting in Chile), F. W. Pavy (a pioneer in the study of diabetes), Frederick Dyson Perrins (pharmaceutical chemist), and Henry Condy (chemical manufacturer). In the next five years there emerged Edward Divers, Herbert McLeod, and Sir William Perkin, the last of whom made his discovery of the first artificial dye in 1856 while he was a research assistant in the College.

FIGURE 1 – *Royal School of Mines, Prince Consort Road, South Kensington.*

FIGURE 2 – *City and Guilds College, Exhibition Road, South Kensington.*

FIGURE 3 (*above*) – *Imperial College Union, Prince Consort Road, South Kensington.*

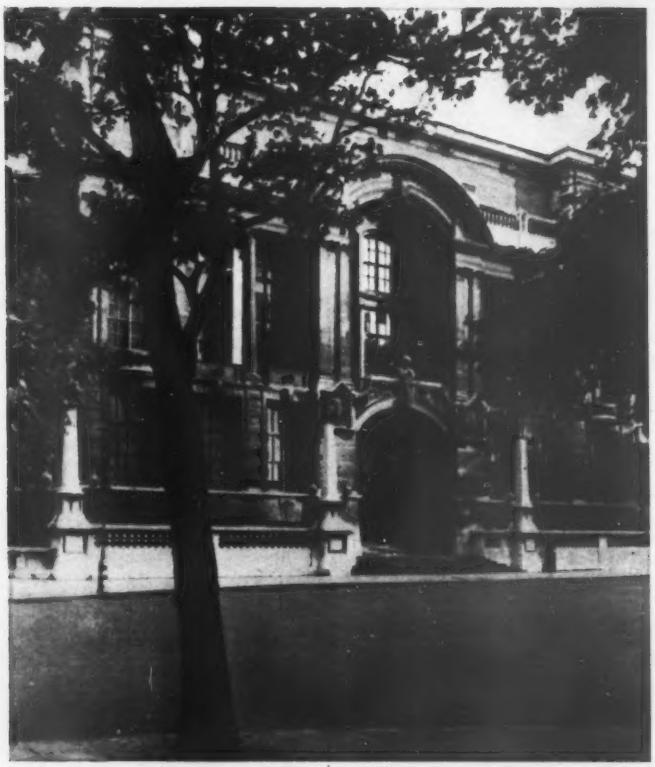


FIGURE 4 (*left*) – *Royal College of Science. Departments of Chemistry and Physics, Imperial Institute Road, South Kensington.*

In 1851 (the year of the Great Exhibition in Hyde Park) the Government provided new accommodation in Jermyn Street for the Geological Survey and Museum, and de la Beche was enabled to put into effect his long-harboured plan for using the resources of the Museum as a basis for organized courses in mining and applied science. The Government School of Mines and of Science applied to the Arts was opened on 6th November, 1851. Its staff, which was drawn from that of the Survey, comprised Warington Smyth (Mining and Mineralogy); Andrew Ramsay (Geology); John Percy, who later came to be known as 'the father of English metallurgy'; Robert Hunt (Mechanical Science); Edward Forbes (Natural History applied to Geology and the Arts); and Lyon (afterwards Lord) Playfair (Chemistry applied to the Arts and Agriculture). It was subsequently said of this remarkable team: 'Rarely in any country, probably never in England, was a more brilliant and gifted staff brought together for teaching purposes than those who, under Sir Henry de la Beche, established a mining school in London, 1851.'

Two categories of students were received at the school: 'associate' students, who took the full-time professional mining course leading to the diploma of associateship of the school, and 'occasional' students, comprising at first 'chiefly soldiers, a few ladies and philosophers . . . and pupils of the School of Design,' who took only selected parts of the course or lectures in a particular subject. The latter were the more numerous, but it was on the former that the reputation of the school was based. As de la Beche's successor, Sir Roderick Impey Murchison, remarked, 'I view it simply as the school of British geology and mines: the affiliated sciences are all subordinate to that fundamental point.' The Prince Consort, however, hoped to see the school develop into 'a Government educational establishment for the diffusion of science generally, as applied to productive industry,' and the newly formed Science and Art Department of the Board of Trade pressed for a widening of the scope of the instruction to this end. Through their efforts the name of the institution was altered in 1853 to the 'Metropolitan School of Science applied to Mining and the Arts,' but the change was more apparent than real, for there was in fact neither money nor accommodation to provide for the proposed extension of activities. The professors realized this, and although some, like Thomas Henry Huxley (who had succeeded Forbes as Professor of Biology in 1854), were supporters of the wider view, they were not prepared to endanger the development of the associateship course by merging it in a general school of applied science. Murchison harnessed the forces of reaction and managed to get the name of the institution changed in 1857 to the 'Government School of Mines,' and finally, in 1863, to the 'Royal School of Mines.' The title of the diploma was altered—retrospectively—to 'Associate of the Royal School of Mines' (A.R.S.M.). The output of associates was never large, but included in the period from 1851 to 1872 men such as Hilary Bauerman, H. F. and W. T. Blanford, Sir Clement LeNeve Foster, Benjamin Peach, George M. Dawson, Percy Carlyle Gilchrist, William Gowland, Hugh Miller, and Sir William Chandler Roberts-Austen—men who subsequently played leading parts in the advancement of science and its application to the development of the mineral resources of the world.

Throughout this period, however, laboratory facilities for the study of the 'other sciences,' especially biology (under Huxley) and physics (successively under Sir George Stokes and John Tyndall, as visiting professors), were almost entirely lacking. That the position was different in chemistry arose from the fact that when Playfair left the school in 1853 the laboratories of the Royal College of Chemistry in Oxford Street had been taken over by the Government, and the College 'incorporated' with the Jermyn Street institution as its Chemistry Department, with Hofmann as professor. By this arrangement the place of practical chemistry in the mining school course was assured. Moreover, the Royal College of Chemistry, thereby relieved of financial difficulties that had arisen through its dependence on private funds, retained a considerable measure of autonomy as a school of chemistry, and under Hofmann and his successor, Sir Edward Frankland, continued until 1872 to enrol its own students and to bestow its own Associateship. Among its alumni in the 'sixties were Sir William Tilden, Lord Shuttleworth, H. E. Armstrong, A. S. Herschel, J. A. R. Newlands, and Sir Alexander Pedler.

In 1870 a Royal Commission recommended that the Royal School of Mines be removed to South Kensington and there consolidated with the Royal College of Chemistry. This proposal, involving the separation of the mining school course from the Museum, was strongly resisted by Murchison, Warington Smyth, and Percy, but it

had to be recognized that if instruction in the other sciences was to be effectively developed, as Huxley demanded, the necessary accommodation would have to be found elsewhere. The Government had acquired, some years previously, from the Commissioners of the 1851 Exhibition, about twelve acres of land at South Kensington for the use of the Science and Art Department, and it was on this site that the departments of Biology (Huxley), Physics (Guthrie), and Applied Mechanics (Goodeve)—from Jermyn Street, and Chemistry (Frankland)—from Oxford Street, were rehoused in 1872. The quasi-independent existence of the Royal College of Chemistry thus came to an end; the building in Oxford Street passed into other hands and was subsequently demolished.

The displaced departments were accommodated in a highly ornamented building in the Italian style in Exhibition Road; now known as the 'Huxley Building,' it is still occupied by departments of the Imperial College. No longer subservient to the mining school course, the departments of the Royal School of Mines at South Kensington soon developed as a separate school of science, and when they were joined in 1877 by the Geology Department it became clear that a new order was emerging. The Committee of Council on Education (the forerunner of the Board) was anxious to see established at South Kensington a school devoted to all branches of applied science with a special organization for the training of science teachers, and was prepared to treat the mining and metallurgy course as a subsidiary feature of this programme. A compromise was reached. In 1881, following the transfer of the Metallurgy Department to South Kensington, the school opened under the composite title of the 'Normal School of Science and Royal School of Mines,' with Huxley as its first dean. Officially it was one school organized in two divisions: the department of Mining (which remained at Jermyn Street until the death of Sir Warington Smyth in 1890) and that of Metallurgy constituting the Royal School of Mines, and the remainder the Normal School of Science—renamed the 'Royal College of Science' in 1891. The two divisions came to be regarded, however, as two associated colleges, each with its own character and traditions and with separate diplomas—A.R.S.M. and A.R.C.S. Among those trained there in the period 1872–1900 were William Frecheville, Sir Charles V. Boys, W. R. Hodgkinson, Henry Louis, E. T. McCarthy, P. F. Frankland, R. D. Oldham, W. H. and A. G. Perkin, Thomas Turner, F. W. Harbord, F. Merricks, J. G. Lawn, S. J. Truscott, W. H. Merrett, S. W. Smith, and L. L. Fermor—at the Royal School of Mines; W. P. Wynne, Alfred Fowler, A. E. H. Tutton, H. G. Wells, F. W. Lanchester, Sir Richard Gregory, Sir Albert Howard, F. C. Lea, W. H. Eccles, Sir Gilbert Morgan, Sir Frank Smith, James Whitehead, Sir Herbert Wright, and L. Bairstow—at the Royal College of Science.

While the Royal College of Science and the Royal School of Mines were emerging in their modern forms, steps were being taken towards the foundation of the other great institution that was to be associated with them. In 1878 the Livery Companies of the City of London created the 'City and Guilds of London Institute for the Advancement of Technical Education.' This body placed in the forefront of its programme the establishment of a 'Central Institution for the advanced education of those who had acquired sufficient knowledge of science or the arts to profit by instruction in the industrial applications of these.' A building for this purpose in Exhibition Road was completed and opened to students in 1884. Although it had been intended that the courses should cover most branches of technology and the decorative arts, the professorships were limited to four in the first instance: Engineering (W. C. Unwin), Chemistry (H. E. Armstrong), Mechanics and Mathematics (Olaus Henrici), and Physics—subsequently Electrical Engineering—(W. E. Ayrton). The diploma of the College (A.C.G.I.) soon became well known in the field of engineering. In 1893 the name of the College was changed to the 'Central Technical College' and in 1907 to the 'City and Guilds College.' Among 'Old Centralians' of the period 1884–1900 the following may be mentioned: Sir Alfred Chatterton, H. A. Humphrey, W. E. Sumpner, E. F. Armstrong, W. du B. Duddell, D. W. Dye, Sir William Pope, C. V. Drysdale, M. J. P. O'Gorman, F. Twyman, Sir Ernest Dowson, and Ralph Freeman.

Since 1884, then, there had existed at South Kensington three institutions devoted to scientific and technological education and research. All were developing rapidly and soon became pressed for accommodation—a pressure which was partly relieved in the Royal College of Science by the provision in 1906 of a new building for chemistry and physics. In the scope of their work the three colleges were largely complementary, and in 1906 a Departmental Committee of the Board of Education put forward a scheme for their closer

co-ordination: 'The main object is the establishment at South Kensington of an institution or group of associated colleges of science and technology where the highest specialized instruction should be given and where the fullest equipment for the most advanced training and research should be provided in various branches of science, especially in its application to industry.' On 8th July, 1907, the Imperial College of Science and Technology was established by Royal Charter. The Royal College of Science and the Royal School of Mines were transferred forthwith to the Governing Body of the new institution, but the City and Guilds College did not become a 'constituent college' until 1910, when there was established for its administration a Delegacy responsible dually to the Imperial College and to the City and Guilds of London Institute. The Imperial College as a whole was recognized as a 'School' of the University of London.

The period since then has been one of steady progress. New buildings have been erected in South Kensington for a Students' Union (1910); for the Royal School of Mines and as the Goldsmiths' Extension of the City and Guilds College (1913); for chemical technology, including chemical engineering (1914); for biochemistry and plant pathology (1923); and as students' hostels (1926, 1931). In addition to accommodation in Exhibition Road, Imperial Institute Road, and Prince Consort Road, South Kensington, the College also has a Biological Field Station at Slough, and a mine—the Tywarnhale Mine, near Truro, Cornwall—where instruction in mine surveying is given. New fields of study and research have been opened up, and the principal departments in the College are now as follows: Botany, with Biochemistry; Zoology and Applied Entomology; Chemistry; Physics, including Technical Optics; Meteorology; Geology, with Mining Geology and Oil Technology; Metallurgy; Mining, including Mining Engineering; Mathematics and Mechanics; Civil Engineering and Surveying, including Hydraulics, Highway Engineering, and Concrete Technology; Mechanical Engineering and Motive Power; Electrical Engineering—Power and Telecommunications; Chemical Engineering and Applied Chemistry; Aeronautics.

In the evolution of the Imperial College the diverse visions of the Prince Consort, of de la Beche, of Huxley, and of the City Fathers—the founders of its component institutions—have all been realized in ample measure, though perhaps not always in the manner first intended. Looking back over the past century, one cannot help being impressed by the extent to which the original institutions developed on lines that enabled them later to be fused into a homogeneous whole; little had to be discarded at any stage. The fundamental aims of the component bodies had always been similar, although changing circumstances brought variations from time to time in their short-term policies. Thus, at one time the training of science teachers was recognized as a most urgent requirement, as was emphasized in the formation of the Normal School of Science. But since the federation, under the guidance of successive Rectors—T. W. Bovey, Sir Alfred Keogh, Sir Thomas Holland, Sir Henry Tizard, and now R. V. Southwell—the predominant objective has been the provision of trained scientists and technologists for direct service to industry and agriculture in this country and overseas.

A strong bias towards experimental work conducted by students themselves has long characterized undergraduate courses in the College. Contacts with industry have been close, and the building up of vigorous schools of research in most departments of the College has greatly enhanced its prestige throughout the world. Before the recent war increasing numbers of post-graduate students were coming from overseas, especially from the Dominions, for advanced study and research, and a resumption of this welcome invasion on a still larger scale may now be expected. New links have already been established with sister institutions overseas by the conclusion of friendly agreements with the Massachusetts Institute of Technology in the U.S.A. and the Indian Institute of Science at Bangalore.

In entering upon a new century of activity it is realized that there is much to be done—and not only as regards teaching and research. For many years numerous students' societies and clubs have flourished in the College, and several, such as the Imperial College Boat Club, have achieved high reputations in their respective fields. But limitations of residential accommodation—always a difficulty in London—have prevented many students from obtaining full benefit from these organizations, which have such an important part to play in the building of character. It has been decided, therefore, that the centenary shall be marked by a resolve to do everything possible to develop a fuller corporate life in the College so that it may the better be enabled to serve the needs of the community in the years to come.

Coral reefs

T. A. STEPHENSON

In this article, illustrated by his own paintings, Professor Stephenson gives a remarkably vivid account of the appearance of typical coral reefs as seen by one who is both a biologist and a connoisseur of beauty. Such accounts are all too rare in biological literature. They provide a most valuable supplement to the preserved material, photographs, and purely technical papers on which the great majority of biologists have to base much of their work.

The plates illustrating this article are reproductions of oil sketches made on the Great Barrier Reef of Australia during the course of an expedition which carried out a biological and geographical study there in the years 1928–9. The results of the expedition's work have been issued in several volumes by the British Museum (*Great Barrier Reef Expedition*, 1928–9, 'Scientific Reports,' 1930 onwards), but these sketches have not before been published.

Coral reefs are as various in appearance as gardens, fields, or any other landscape features, and on any one reef a great variety of scenery may be visible. Moreover, although coral reefs are rocky structures built up from the skeletons of living organisms (corals, algae, and various invertebrates other than corals), they vary very much in the extent to which they are 'alive.' Apart from reefs which are dead altogether (i.e. which were constructed in earlier times), there may be found reefs on which the living and growing coral is so small in amount as to be inconspicuous, the bulk of the reef consisting of dull grey eroded rock of dreary aspect, offering little to attract the eye but for individual plants and animals inhabiting pools on its surface, among which may be seen, perhaps, a starfish marked by a pattern like that of a Turkey carpet or another the colour of washing-blue. Even on a reef which has round its edges a rich and healthy growth of living coral, it is often possible to walk for miles without seeing any. The tops of such reefs form immense sandy flats, with dingy grey boulders or patches of dead coral rock in varying amounts, and with trailing dull green or even blackish plants growing in or on the sand. There may be innumerable pools, the populations of which sometimes show more varied forms and brighter colours; but to see the coral growth at its best one must look for it at the seaward edge of an actively growing reef, where, from about the level of low water of spring tides downwards, the whole slope will be carpeted with a bewildering array of form and colour which rivals anything to be seen on earth.

As a contrast to the somewhat dingy picture conjured up by half-dead reefs and endless sand-flats, we may describe one of the reefs forming the oceanic edge of the Great Barrier. These 'Outer Barrier' reefs form a line of ribbon-like strips with gaps between them, which separate the Pacific Ocean from the shallower waters of the lagoon between them and the mainland. One of these ribbons, known as Yonge Reef, was visited by several of us in 1929. Here, almost every aspect of the landscape was full of colour and brilliance, and we were in a world utterly unlike anything familiar to us. The sense of unreality was extraordinary. On the one hand was the great line of Pacific breakers crashing down with immense power on the seaward edge of the reef; yet the reef destroyed their force so effectively that it was possible to stand within a few yards of them and to see submerged corals on the slope below them reflected in their curling crests before they broke, and to look down into clefts in the edge of the reef at such corals themselves. That the reef should check the breakers so effectively seemed the more amazing in that it was itself so low, so flat, so apparently powerless; it is a reef which at high water is completely submerged by the sea, and which emerges very little above sea level even at the lowest spring tides. The ability of individual corals to withstand the direct shock of the breakers enhances this impression. That some of them should do so is understandable enough, because they have massive forms which can be detached from the reef only with difficulty, with the help of hammer and cold chisel; but others are so slightly built that the least tap from foot or chisel will shatter them, while they withstand the crash of the breakers uninjured. The highest part, or crest, of this ribbon

PLATE 2 – *A giant clam* (Tridacna derasa) *in a shallow pool on the reef flat at Low Isles, Queensland. The rounded masses to right and left of the clam are living corals* (Porites); *the branching growth* (top right) *is another species of coral* (Montipora ramosa); *the curled fronds* (top left) *a seaweed* (Padina); *the honeycomb-structure* (bottom left) *another coral* (Goniastrea). *The blue starfish is* Linckia laevigata.

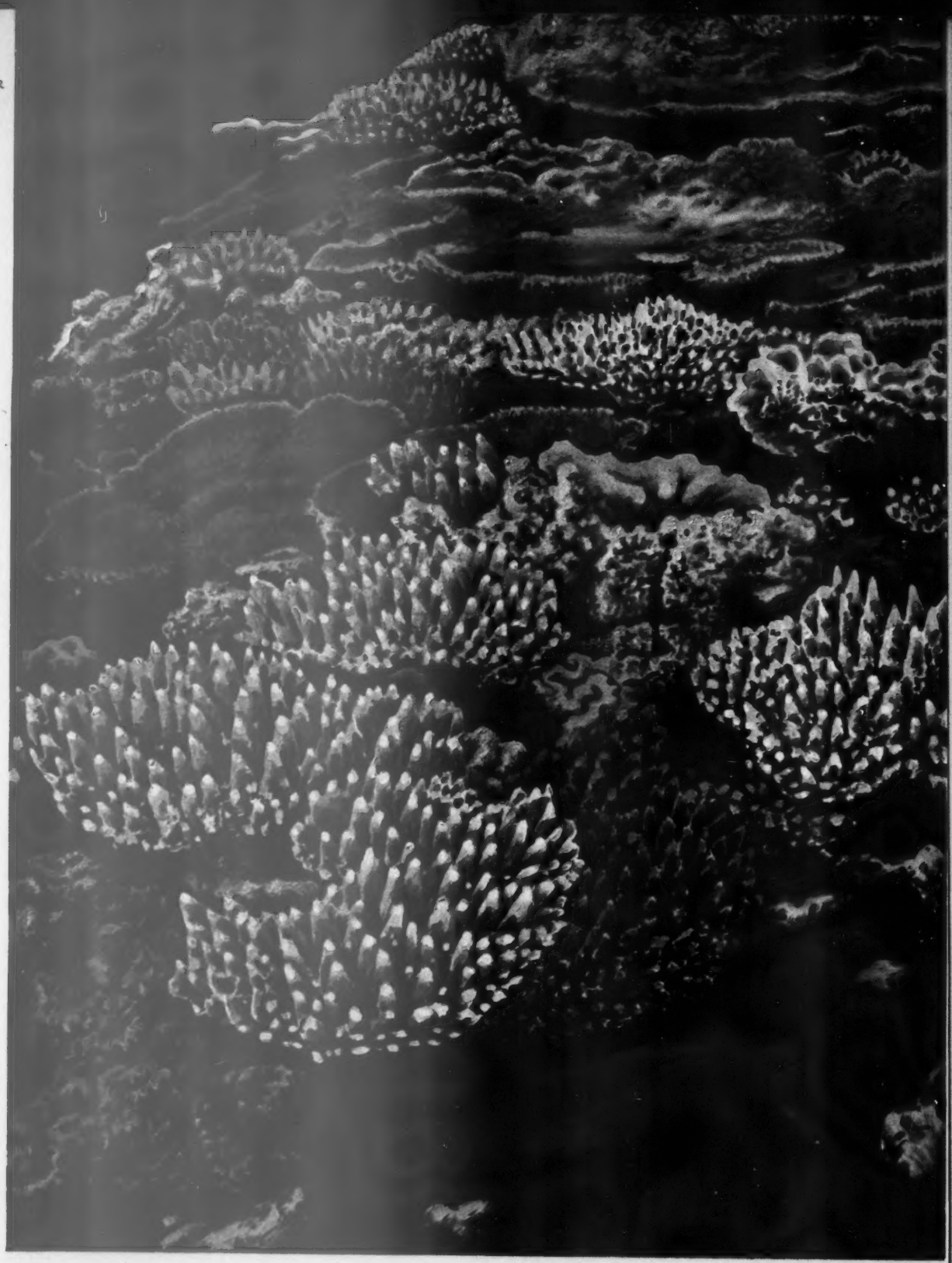
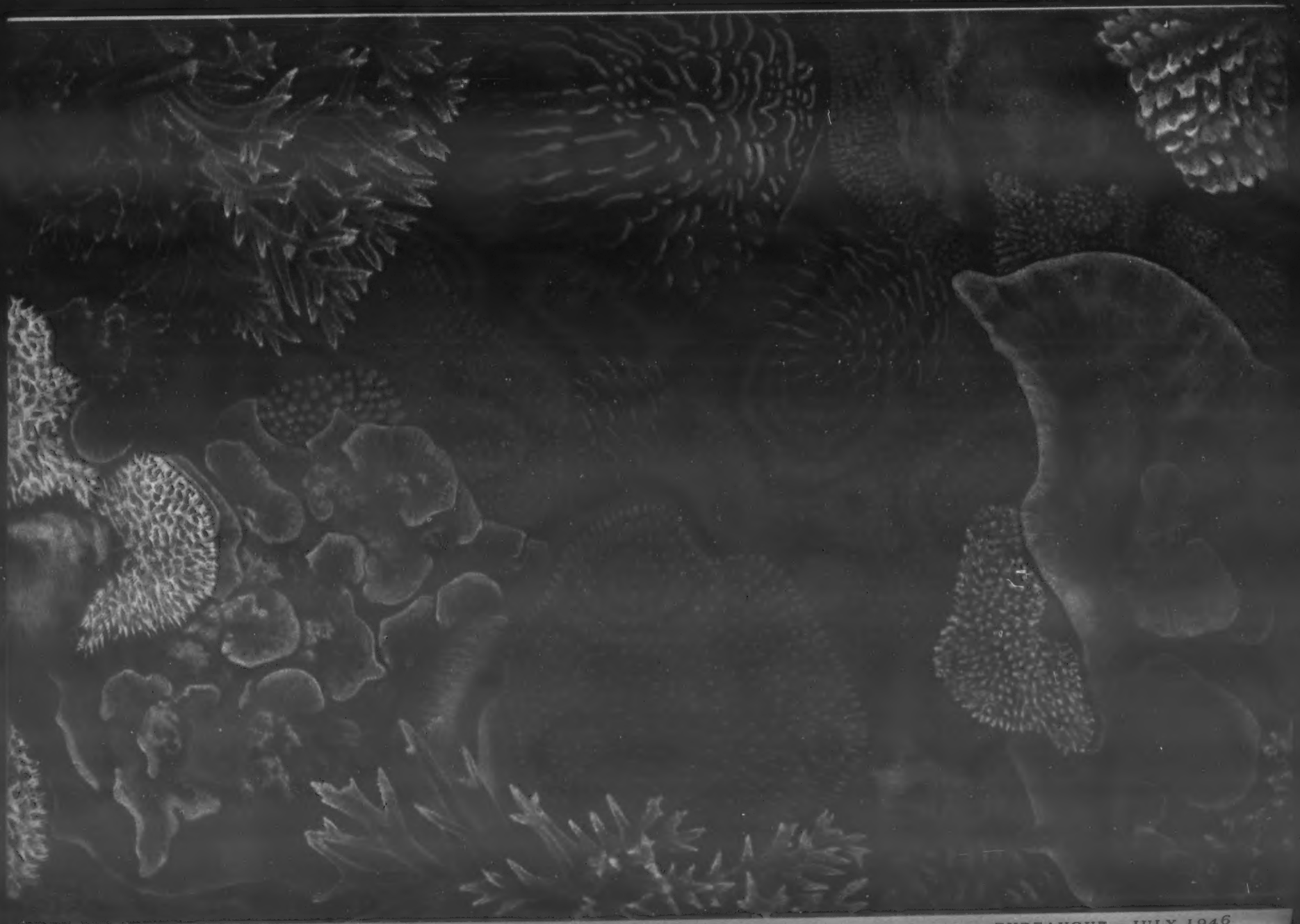


PLATE 3 – *A growth of living coral on the top of a small coral islet on the landward side of Yonge Reef, Outer Barrier, Queensland. All the coral visible belongs to the genus* Acropora *(the leading reef-builder), but is very variable in form from one species to another. The yellow and violet colonies with thumb-like branches are* A. gemmifera, *the brownish brackets with pale edges* A. hyacinthus, *the irregular cream-coloured shapes* A. palifera.



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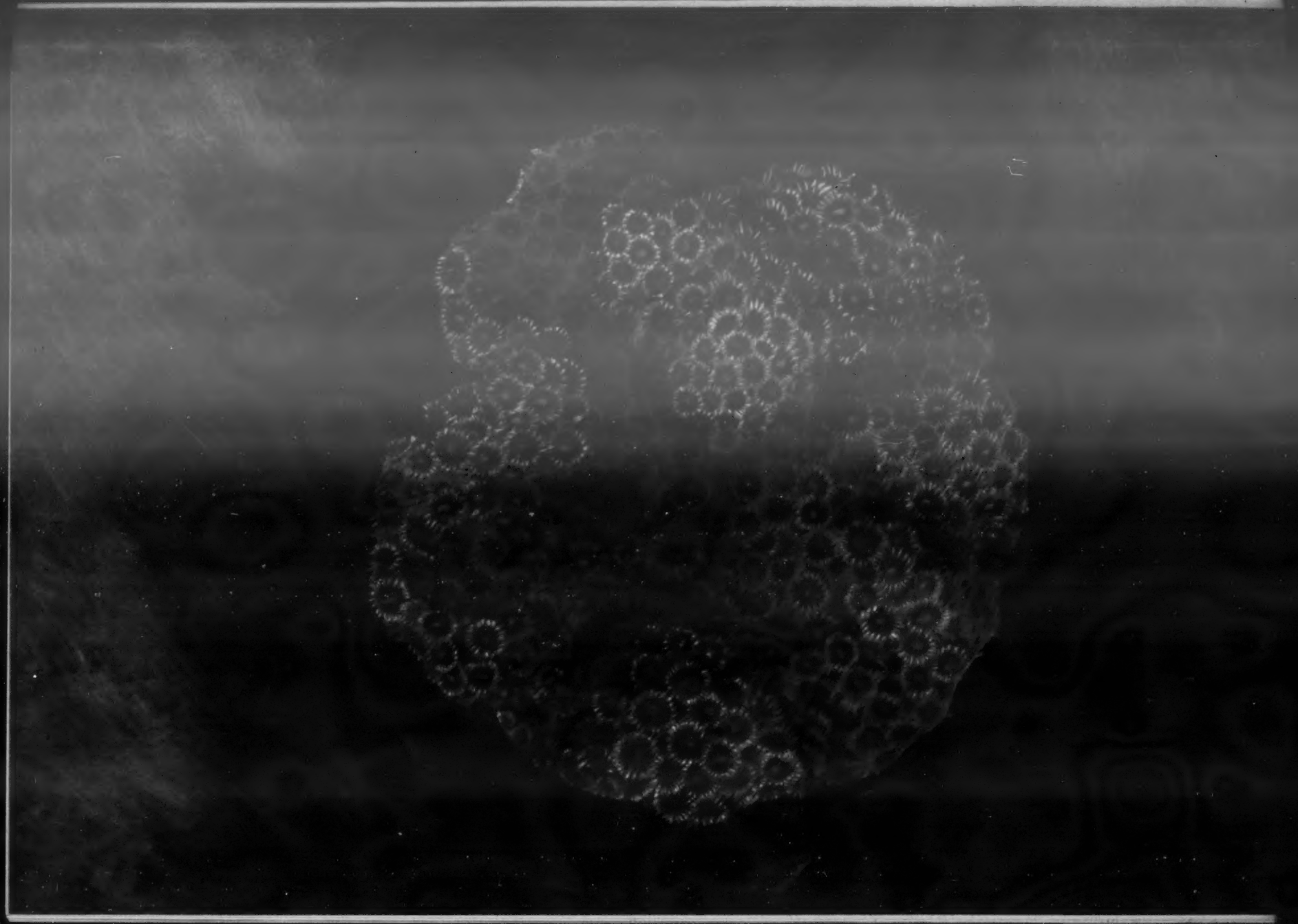

PLATE 8 – *View of part of the landward side of Yonge Reef, Outer Barrier, from the deck of a motor-launch. The mountain is Lizard Island, and beyond it the Queensland mainland is visible. The bright blue and green water is shallow water over white sand, and the dark line below the mountain is the deeper water of the lagoon between barrier and mainland. For further description see the text.*

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of reef has the form of a wide low ridge about 160 yards wide and over three miles long, set back about 100 yards from the breakers. This ridge gives the effect of a broad carriage-drive isolated in the ocean, with the breakers along one side and the brilliantly coloured water to landward of the reef on the other. The colour of the ridge itself is by no means drab; the ground is pink, being covered by a crust of corallinaceous algae, and from this pink background arise corals and other organisms showing a wide range of different colours. The colours in the hollows and on the coral masses between the ridge and the breakers are even more varied and beautiful. A scene of another type is provided on the sheltered side of the reef away from the breakers, and this is illustrated in plate 8, which was sketched from the deck of a motor-launch anchored as near to the main reef as was safe. The reef breaks up, on this side, into a great many separate islets of coral, many of them with precipitous or overhanging sides, arising from a floor of extremely clean white sand or gravel. The tops of these islets just appear above sea level at extreme low water, and some of them are seen in the foreground, covered with living coral. The brightest colour, however, is provided by the water itself. This, varying from a brilliant green in the shallows to a bright blue where it deepens, is far from being exaggerated in the sketch; it has a lambent flame-like quality which cannot be reproduced in paint. The shallow water, against the white paint of the launch, had the quality of a copper flame, the slightly deeper water rather that of a sunlit solution of copper sulphate.

When it is possible to see a coral reef as a whole, from a distance, its appearance varies according to its nature, and two examples may be seen in plate 1. This was sketched from near the top of the 1,100 ft. mountain (Lizard Island) which is seen on the horizon in plate 8. In the foreground, beyond the foothills of the island, are seen irregular coral reefs shown as purplish patches in the shallows. Out to sea are three large reefs (Eagle Island reef, M reef, and L reef) rising from the floor of the lagoon between Outer Barrier and mainland (seen in the distance). Large and solid though these reefs are, they seem, from such a height and distance, to float on the sea like wraiths.

A scene very different from what has already been described is presented if one descends below the surface of the sea, among the growing coral itself, with the assistance of a diving-helmet. Beneath the sea one is in another world at once, cut off completely from that we know. The surface makes an absolute barrier, a roof through which nothing can be seen; the sea in fact has become sky. It is a far more limited sky than ours: it contains infinitely less depth and distance, and is usually of a delicate bluish green, but shading away at the edges as if it were sky. Sunlight filters down through it with a distinctly strange effect. As a rule, the landscape is all foreground with vague shapes behind, and there is no distance. The scene begins with a floor of sand and stones, with corals mounted on some of them. From this floor rise towering rocks, ending above one's head, which sometimes attain the dimensions of cliffs. From the sides and tops of these spring corals of every size and colour. There are delicate branching sprays; rounded forms; antler-like formations; and, above all, spreading vase-shaped or bracket-like structures, some of which reach as much as eight feet across and will support the weight of a human being. The scene is invariably enlivened by the presence of numbers of small fish. Tiny green or yellow ones swim in and out among the branches of a fawn-pink coral, perhaps as many as fifty of them to a single colony. Larger fishes of the most bizarre shapes and colours are present also, in smaller numbers—black and gold, electric blue and gold, striped like a zebra, or showing all the colours of the rainbow at once. These fish usually take no notice at all of a diver, unless he makes a sudden movement in their immediate direction.

It is sometimes supposed that the colours to be seen on coral reefs are universally brilliant. This is a mistake. It is true that in the most highly coloured parts the variety of shades is very great, and this forms part of the attraction. But very often the prevailing tints are yellowish brown or pinkish brown, with a brilliant contrasting note here and there. The beauty, which is very real, depends by no means on brilliance alone, but also on variety of form, and more particularly upon texture. The corals often have a strangely velvety appearance, in strong contrast to their actual hardness. The perfect delicacy of form and colouring, the fineness of grain and texture, and the change of colour which so often occurs at the tips of growing branches (as, for instance, from fawn to vivid hyacinth blue), produce an effect which defies description. Two of the accompanying plates (3 and 4) show the general appearance of coral growths seen at close quarters, but unfortunately one cannot pass on the exquisite texture without spending far more time on the drawing than was available. Plate 3 shows coral

exposed to the air at the time of low water, on one of the islets to landward of Yonge reef; plate 4 shows a growth on another reef, as seen just below the surface, at low water, from an anchored dinghy.

The actual animals (polyps) which produce the coral are similar to sea anemones, and are carnivorous, however flower-like they may appear. The colours of the living coral reside not so much in the tentacles of the polyps as in their bodies and the tissues which connect them; it is the whole film of flesh covering the skeleton which is coloured. The tentacles of the polyps, however, are not usually seen by anyone visiting the reef in daylight, because most of the polyps expand and feed only or mainly at night. There are exceptions to this, and two of them are illustrated in plates 5 and 7. In plate 5 are seen several unusually large polyps belonging to a species of mushroom-coral (*Fungia*), expanded in daylight among the dead and living coral in a shallow pool. Plate 7 shows a colony belonging to a species of *Turbinaria*, a wavy dish-like structure covered on its upper side by expanded polyps. The remaining plates illustrate some of the other animals common on Australian reefs. In plate 2 a giant clam (*Tridacna*) is seen surrounded by living coral and seaweed; plate 6 depicts a giant sea anemone (*Stoichactis*), its Prussian-blue tentacles making a curious contrast to its dull background of dead coral with pinkish algal encrustations.

Mention has already been made of small green and yellow fish which swim in and out among the branches of some of the corals. These fish illustrate an occurrence which is very commonly seen on coral reefs—the close association of animals of quite different kinds which is known as 'commensalism.' Thus, in the case already mentioned, each coral colony possesses its own exclusive shoal of fish, which apparently never venture far from the shelter of the branches. Other corals are often accompanied by crabs or prawns. There is, for example, a very common yellowish-brown branching coral (*Pocillopora bulbosa*) living in shallow pools on the tops of reefs, which frequently shelters a beautifully coloured red and purple crab (*Trapezia cymodoce*) about an inch across; and the same coral less often harbours small crabs of other species, or prawns. Prawns, in fact, are among the commonest commensal animals, and brightly coloured species of the genus *Periclimenes* often make their headquarters not only with corals but also with sea anemones, which themselves may shelter not only prawns but fish. The anemone represented in plate 6 (*Stoichactis kenti*) is unusual in several ways. In the first place it is very large for an anemone (up to eighteen inches or more in diameter), secondly it is often bright blue, which is not a common colour in anemones. Thirdly, it often shelters small commensal prawns (*Periclimenes*) and fish (*Amphiprion* and *Actinicola*) which are strikingly unlike it in colour. The whole question of the coloration of commensals is one which would repay further study. While many of them tone in with the coral they inhabit, so that they form a part of its own colour scheme, others contrast with it quite sharply and yet produce no inharmonious effect, as when brilliant golden-yellow fish live with a pinkish brown coral. On the other hand, some of them—and this applies to crabs, prawns, and fish—adopt a very peculiar colour scheme which is quite out of harmony with the background colour of the anemone or coral, and reminds one forcibly of a vividly striped football jersey. These species exhibit variations on one combination of colours—black, scarlet, and bright opaque cream, arranged in stripes and making them very conspicuous. This particular coloration is found in the fish and prawns mentioned in connection with *Stoichactis*, and again in some prawns which we saw one day when diving in about five fathoms of water. On this occasion a coral about two feet across had its polyps expanded so that the whole colony was covered by a carpet of dull brown knobbed tentacles; and among the tentacles were about two dozen of these striped prawns of various sizes, all exhibiting the curious swaying motion, as if combing the tentacles, which is characteristic of them, giving the extraordinary effect of a brightly coloured submarine ballet. The striped colour scheme is seen again in a small crab of unique habits, which we did not see on the Australian reefs although we found it under dead fragments of coral on some of the reefs round the island of Mauritius at a later date. This is the well-known (but rarely seen) *Melia tessellata*, and its peculiarity lies in the fact that it habitually carries two small sea anemones about with it, one in each nipper, and when in danger holds them up as if they were boxing-gloves. Naturally the relationships between very different species, of which these are examples, have provided opportunities for studies in animal behaviour of certain types—to what extent the associations are of mutual benefit to the partners, to what extent one exploits the other, and so forth. While there has been a certain amount of recent experimental work which partly answers such questions, there is scope for a great deal more.

The present position of theoretical physics

N. F. MOTT

Investigation of atomic phenomena showed that Newtonian mechanics are not of universal truth. Recognition of this fact was followed by the development of a new system of equations known as quantum mechanics, of which Newtonian mechanics proved to be a special expression valid for relatively large particles. Professor Mott discusses the influence of the theory of quantum mechanics on recent developments in physics, and describes certain phenomena for which even the new mechanics may not provide an explanation.

The interval between the two wars was a period of sensational advance in atomic physics. It saw the first splitting of the atom achieved by man; it saw also the discovery of several new particles, the positive electron, the meson, and above all the neutron, which pointed the way to the atomic bomb; but perhaps in the history of science it will be remembered foremost for the discovery of the system of equations which is known alternatively as quantum mechanics, wave mechanics, or matrix mechanics. Less than a year after the explosion of the first atomic bomb, with its profound effect on the war and on the ensuing peace, it may seem strange to ascribe such importance to a system of equations, especially as, in view of the several different forms in which the theory was introduced and the controversies between scientists and philosophers which attended its birth, it is not generally realized, except by professional physicists, how remarkably successful it has been; but it now appears that we have in quantum mechanics a body of knowledge which in its proper field is likely to last just as long as Newton's laws of motion will last in theirs—which means for just as long as scientists and engineers have a place in civilized communities.

Newton's laws of motion were so successful that until the present century most people believed that they were true for all the phenomena which make up the science of physics. We now know, thanks to the work of Einstein, that Newton's laws break down for particles moving very fast, with speeds comparable with that of light, and that Newtonian mechanics must be considered as a special case of the more general relativistic mechanics, valid only for particles moving with comparatively low speeds. We know also that Newton's laws are not true at all for the very small and light particles (electrons, protons, neutrons) of which atoms and molecules are built up. To explain the behaviour of these particles, quantum mechanics have been developed, and the Newtonian system must be considered again as a special form of quantum mechanics valid for heavy particles like cricket balls, projectiles, or planets. But none the less, in their proper field Newtonian mechanics remain completely satisfactory. No one would dream, for example, of using either quantum mechanics or relativity in ballistics to calculate trajectories of bombs, shells, or rockets; the corrections introduced if this were done would be utterly beyond the possibility of measurement, and so in this field Newtonian mechanics remain true. The same can be said about much of astronomy, especially the calculation of the motion of the earth and the planets round the sun; the Nautical Almanac Office does not need the principle of relativity to predict the date of a forthcoming eclipse.

Quantum mechanics, like Newtonian mechanics, are not the ultimate theory of inanimate nature; but, like Newtonian mechanics, for a very wide class of phenomena they give for all practical purposes the right answer. This class is so wide that until the present century it would have been thought to comprise the whole of physical knowledge. It includes, to begin with, the whole of chemistry, the science that deals with the forces which enable atoms to combine together to form molecules and solids. It accounts with sufficient accuracy for the behaviour of electron beams and thus for electronics generally, and also for nearly all spectroscopy and for the production and properties of X-rays. It is only in those new and, until the atomic bomb, rather remote subjects, nuclear physics, stellar energy, and cosmic rays, that phenomena occur which may not be within the competence of quantum mechanics to explain.

The work of Rutherford and Bohr in the early years of this century established the nuclear model of the atom on a firm footing. The well-known and important features of this model are the

existence of the heavy positively-charged nucleus in the centre of the atom and of electrons which move round it. The only properties of the nucleus that matter for chemistry and for all allied sciences are its mass, which determines the atomic weight of the atom, and the charge, which determines the number of extra-nuclear electrons (the atomic number). On this number depend the position of an element in the periodic table, all its chemical properties, and, except for a few finer details, its optical and X-ray spectra. The complicated internal structure of the nucleus can be revealed only by the special techniques of the high-voltage laboratory or the atomic bomb, and, except for the phenomenon of natural radioactivity, it was quite without influence, as far as we know, on the properties of animate and inanimate matter on this planet until scientists began to investigate it. On the cosmic scale, nuclear phenomena are of course of primary importance, being responsible for the heat and light from the sun and stars; but it is remarkable how little indication the nucleus gives of its inner structure in the behaviour of material things on the earth outside of physical laboratories.

The theory known as quantum mechanics or wave mechanics seems quite sufficient to account for the behaviour of the extra-nuclear electrons. An entirely satisfactory relativistic branch of the theory does not yet exist, though here, too, great progress has been made. Since, however, in atoms and molecules the velocities of the particles are small compared to that of light, this does not matter so far as the applications of the theory to chemistry and to allied subjects are concerned. In this field the findings of the theory seem to be always in agreement with experiment. Calculations based on the theory have been made of the energy levels of various atoms, of the binding energy of some of the simpler molecules and chemical bonds, and of the scattering of beams of electrons by gaseous molecules. The differential equations that have to be solved are complicated, and much numerical work is needed to obtain a fairly exact solution, but when this is done the agreement with experiment is very satisfactory.

During the few years after the discovery of quantum mechanics the theory was rapidly applied to all the simple problems of atomic physics, with uniform success. Thus Heisenberg and Hylleraas gave a treatment of the spectrum of helium, Sommerfeld and Bloch explained the outstanding facts about conduction in metals, and London and Heitler gave the first complete theory of the homopolar bond. It was a golden age for the young research worker, who could perhaps master the ideas of the new mechanics more easily than his seniors, and could then use them to explain phenomena unexplained for a hundred years. That period has now passed. The centre of interest in non-relativistic quantum mechanics has now passed to complicated problems which derive their interest from physical or organic chemistry, metallurgy, or industrial physics. In these fields advances will be made by experimentalists with a good knowledge of quantum mechanics, or by theorists with a very wide knowledge of physics and chemistry; there is little scope there for the research worker whose interest in the subject is mainly mathematical. A particularly promising subject seems to be the study, both theoretical and experimental, of the flaws that exist in solids and their effects on the strength of the solids. In a subject such as this, neither theory nor experiment can make much progress without the other.

In the field of knowledge where quantum mechanics ought to be valid, the outstanding unsolved problem is the phenomenon of superconductivity, or the disappearance of the resistance of certain metals at low temperatures. It is probably true that nearly every eminent theoretical physicist has, at some time or other, tried to explain this property, but without success. The problem of the motion of a large number of interacting electrons in a metal is of course extremely complicated; it is not possible to obtain a solution of the equation of motion without introducing drastic simplifications. When this is done, the equations do not predict that anything like superconductivity should occur, and no one has yet been able to tell whether the exact solutions would do so.

We turn now to the field of nuclear physics and cosmic rays, of stellar interiors and very high energy particles. It is in this field that something totally new is to be found out: it is not a question, for the theorist, of applying known laws to complicated phenomena, because in this field the known laws do not always work, and modifications of a fundamental nature will have to be introduced. The difficulties are twofold—the contradictions in the theory that arise for particles moving with velocities near to that of light (represented by c), and our lack of knowledge of the laws of force between nuclear particles.

The attempt to build up a relativistic form of quantum mechanics has had a most interesting history. The first big step forward was made by Dirac, who showed in 1928 that a relativistic generalization of Schrödinger's original wave

equation could be given if—and only if—the electron was assumed to have a fourth degree of freedom, the so-called 'spin' that spectroscopic evidence had already shown to exist. Dirac's equation was brilliantly successful in explaining the spin itself and in giving a quantitative account of many phenomena in which the spin is involved. Unfortunately, however, it predicted the existence of 'states of negative energy'; according to the theory of relativity, the energy W of a particle of mass m moving with velocity v should be given by the formula:

$$W = mc^2/\sqrt{(1 - v^2/c^2)}$$

and Dirac's equation predicted that both the positive and negative values of the square root should be admissible. Nothing in nature corresponding to an electron with negative energy was known to exist, and Dirac tentatively suggested that the states of negative energy should be 'filled up' by a continuum of electrons, in general not making their presence felt except by keeping other electrons out. This rather strained hypothesis had an astonishing confirmation in the discovery of the positive electron, which finds a ready explanation as a 'hole' where an electron is missing from the continuum. Nevertheless the whole conception leads to many difficulties, especially in the theory of the interaction between radiation and charged particles moving with very high velocity, such as occur in cosmic rays.

The difficulties which occur in nuclear physics are of a somewhat different nature. The whole successful theory of quantum mechanics for the extra-nuclear electrons is based on the assumption that electrons and protons attract each other, and electrons repel each other, according to the law of the inverse square. The nucleus, however, is not built up of electrons and protons, but, according to the most recent theories, of protons and neutrons. The number of protons is thus equal to the atomic number, and the number of neutrons to whatever is necessary to make up the atomic weight. Nothing is known *a priori* about the nature or magnitude of the interaction between protons and neutrons, and thus it is hardly possible to say at present whether quantum mechanics in their present form are applicable to the nucleus or not. Certainly some of their more qualitative features are valid, in particular the existence of quantized energy levels; but it is as yet uncertain whether they would be adequate, once the interaction forces were known, to calculate for example the energy with which two protons and two neutrons combine together to form an α-particle.

At present one of the most interesting and promising lines of investigation is the attempt being made to connect the interaction between proton and neutron with the existence of the new charged particle, the meson, of mass intermediate between the proton and electron, which has been shown to exist in the cosmic rays. A number of meson theories of the interaction exist, but none of them is in entire agreement with experiment. Whether ultimate success will be obtained along these lines, or whether a radically new approach is necessary, only time will show.

An article on the present position of theoretical physics would be incomplete without some mention of the philosophical implications of the subject, although this article gives little space for so large a topic, and any remarks must be coloured by the prejudices of the writer. However, it has to be faced, in his opinion, that the notorious 'uncertainty principle' of Heisenberg has come into science to stay. The hypothesis that it is impossible simultaneously to measure the position and velocity of a particle is deeply embedded in the structure of the quantum theory, and any attempt to remove it would bring the whole theory to the ground. It is not brought forward because of some temporary limitation in the accuracy of our measuring instruments which future experimental work may remove, but much more as a direct deduction from certain experimental facts (electron diffraction), which without the uncertainty principle cannot be explained in any rational way. The tendency at the moment in modern developments, especially those of the Copenhagen School, is to extend the scope of the principle rather than to limit it.

It seems therefore highly improbable that physics will ever revert to the position in which it could be believed that the future was inherent in the present, in the sense that a sufficiently well-equipped computing service would be in a position to calculate the future, if given all the facts about the motion of all the particles in the universe at the present time. The equations of mathematical physics appear to preclude any such ambitious project, whatever the resources that the imagination can assign to it. The contribution to philosophy of recent discoveries is therefore rather negative; certain statements about the mechanistic nature of the universe that were made in the last century may have to be withdrawn, or at any rate cannot command the authoritative support of science. Positive conclusions can also be drawn but are outside the present scope.

Moulds and tropical warfare

G. SMITH

Even in temperate zones the damage to property resulting from the activities of biological agents, of which moulds are among the most destructive, is of considerable economic importance. In the tropics, where ideal conditions for the growth of moulds are of common occurrence, the destruction can be very serious indeed. This fact was very forcibly demonstrated during the recent war; the methods then devised for the protection of military equipment can in many instances be profitably applied in domestic and industrial fields.

The war with Japan created numerous problems for our armies and those of our Allies. Many of them, in particular the appalling difficulties of jungle fighting and the severe strain on human endurance, have been given some publicity, but less has been heard of a campaign against the enemies which attacked equipment and thus very considerably reduced the efficiency of the fighting forces.

During the early part of the Far Eastern war, losses of food, clothing, shelter, tools, arms, ammunition, and especially of the many precision instruments used by a modern army, were on an alarming scale. Much of the damage could be traced to faulty methods of packing, methods which made insufficient allowance for the inevitable rough usage to which stores were exposed in very difficult country. There remained of the total loss, however, a high percentage which was due to the activities of biological agents, and the principal offenders were moulds.

Damage due to micro-fungi is a serious matter even in this country, but under jungle conditions it is many times worse. Growth of moulds is always associated with a humid atmosphere, and the higher the relative humidity the more rapid is growth and the more varied is the micro-flora. In the jungles of Burma and the Pacific Islands, where most of the fighting occurred, the relative humidity may lie between 90 and 100 per cent. for considerable periods, with little variation between night and day. Under these conditions, mould growth on susceptible materials is extremely rapid, and it is not easy to design equipment which will give satisfactory service over a reasonable period.

Early in 1943 the Ministry of Supply initiated a programme of research on methods of tropic proofing. A number of advisory committees were formed, composed of representatives of the Services and of a number of scientific institutions. A test chamber was fitted up at the London School of Hygiene and Tropical Medicine, in which atmospheric conditions were maintained to imitate as closely as possible those obtaining in tropical jungle. After study of meteorological data for various stations within the war zone, it was decided to maintain a day temperature of 85° F (30° C), with a relative humidity between 98 and 100 per cent. and very slow circulation of the air. The temperature was allowed to fall naturally at night, resulting in supersaturation and then condensation, very much as happens during the night in the jungle. In the beginning, the chamber was thoroughly inoculated with a number of species of moulds which were known to grow on stores in the tropics, and, for a time, all materials put in the chamber for test were similarly inoculated. Soon, however, it was found that a micro-fauna, chiefly psocids and mites, had colonized the chamber, being attracted by the warm, humid conditions, and inoculation became unnecessary, since these creatures distribute mould spores quite efficiently. For the testing of hundreds of small samples it was found more convenient to incubate in glass vessels containing water to maintain a saturated atmosphere. These were incubated in a constant-temperature room at 30° C, and test samples were always inoculated.

For some time the original equipment was adequate to deal with the programme of research, but eventually the demands of all three Services increased to such an extent that the work had to be shared between a number of establishments, and several other tropic chambers were put in commission. Nor was work on the mould problem confined to Britain, for at an early stage parallel investigations were undertaken in Australia and the U.S.A. In order to prevent undue overlapping there was close collaboration from the very beginning, with free interchange of reports between the three countries.

It would be impossible to give here an adequate

FIGURE 1 – *Mould growth in a wireless set. Hyphae bridging some of the components.* (By courtesy of the Ministry of Supply.)

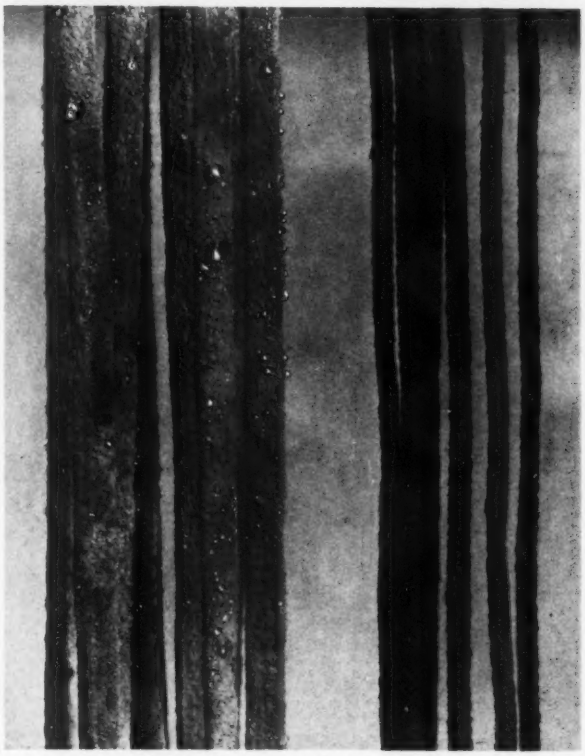


FIGURE 2 – *Fabric bootlaces after incubation in a 'tropic chamber.' (Left): Unproofed. (Right): Chrome-proofed.*

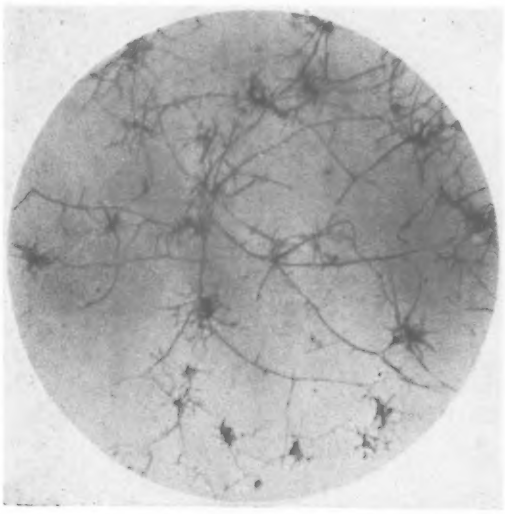


FIGURE 3 – *Mould on prism.* (× 25.)

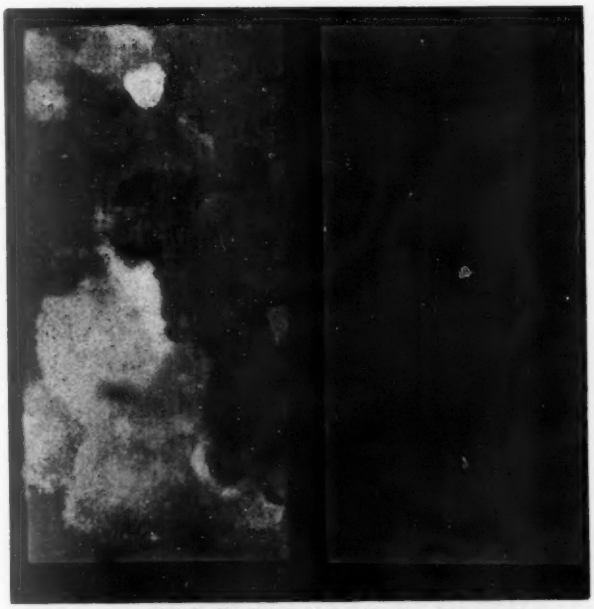
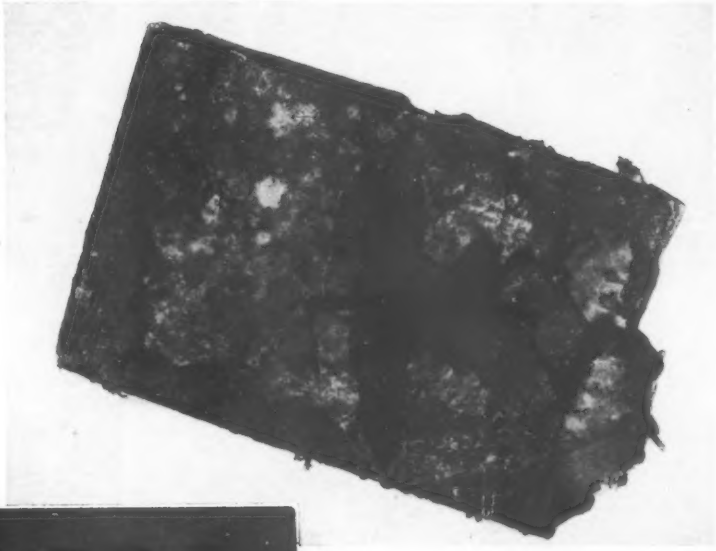


FIGURE 4 – *Fabric-filled bakelite. (Left): Unscoured fabric. (Right): Scoured fabric.*

FIGURE 5 – *Binocular, fitted with capsules containing silica gel, after two months under tropical conditions. Outside corroded and slightly mouldy. Inside in good condition.*

FIGURE 6 – *Instruction booklet almost completely disintegrated by moulds and moisture.*



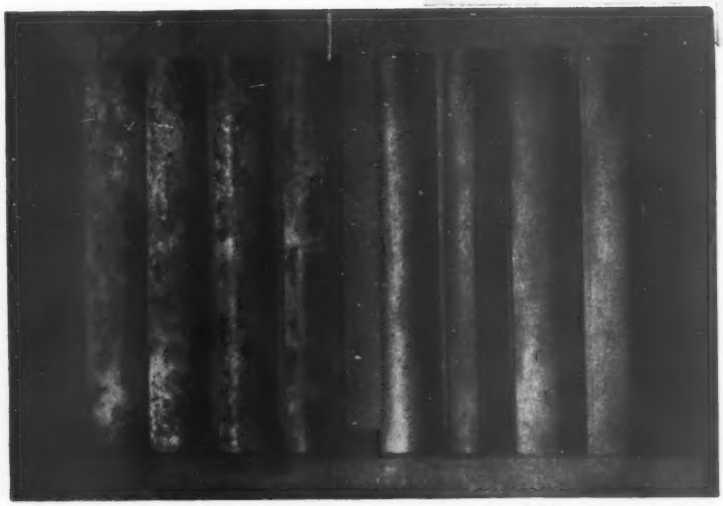


FIGURE 7 – *Rolled paper ammunition tubes. (Left): Casein glue. (Right): Urea-formaldehyde glue.*

account of all the lines of investigation which have been followed. Only a few, therefore, of the more important methods of mould-proofing will be described.

ELECTRICAL EQUIPMENT

The first urgent problem to be attacked concerned the occurrence of mould in wireless sets and similar apparatus. Figure 1 shows part of the inside of a service wireless set attacked by mould, hyphal strands bridging various components being clearly visible. This kind of damage occurs mostly in store before sets are issued, since, when a set is in use, considerable heat is generated, sufficient to dry out the set and to kill most moulds, and, if there are no long idle periods, any mould growth which occurs will never reach the stage shown in the photograph. There is seldom any direct destruction of insulating materials, even when mould growth is extensive, the danger being from leakage between high-tension circuits along the moisture-laden hyphae.

The provision of mould-proof wireless sets is no easy matter, but much progress towards a solution of the problem has been made by building sets entirely from materials which will not provide food for moulds. The more important of the alterations which have been made have been the substitution of plastics (chiefly polyvinyl chloride, 'P.V.C.') for fabric insulation on conductors, the careful selection of waxes and other impregnating compounds, the complete elimination of cork packing and insulation, the use of paints containing fungicides, and the restriction of the use of laminated plastics to those containing inert or suitably protected fillers. However, re-design is only a partial solution, and, in order to provide protection for sets already manufactured and issued, methods of spraying or painting with lacquers containing fungicide have been developed. These lacquers are not easy to apply, since a good deal of preliminary masking of metallic contacts has to be done, and the final result is not a permanent protection. Nevertheless, if lacquering is carried out intelligently, it certainly serves to cut down replacements very considerably.

FABRICS

Fabrics of various kinds form parts of so many items of equipment that they have naturally received much attention. Fortunately a large amount of research had been carried out before the war by the research associations, in particular the British Cotton Industry Research Association, and the solution of wartime problems was often a question of adapting existing knowledge rather than seeking new methods of proofing. 'Shirlan' (salicylanilide) has been used extensively in clothing and bedding, that is in fabrics which require protection during transport and storage but which, after issue, are either frequently laundered or worn to destruction. However, in view of the many demands for 'Shirlan' during the war, the supply position soon became serious and substitutes had to be sought. In preliminary tests a number of compounds used as accelerators in rubber manufacture showed considerable promise, and one of these, mercaptobenzthiazole, proved to be quite as effective as 'Shirlan.'

Valuable as these antiseptics are, they cannot be used for any fabrics which are normally exposed to the weather, as they are fairly rapidly leached out. For webbing, waterproof canvas covers, and tent material, chromic oxide is as good as anything found up to the present (see figure 2). For some fabrics it is used alone, at the rate of approximately 1 per cent. of the weight of the material, but it is more usually mixed with ferric oxide to form what is known as 'mineral khaki.' For heavier waterproof sheetings, such as tarpaulins, and for ropes, copper naphthenate has been widely used.

For all fabrics composed of cellulose a very simple method of enormously increasing resistance to moulds is to scour by boiling for at least an hour with a 1 per cent. solution of soda ash. Very few organisms can attack pure cellulose, and the liability of fabrics to become mouldy is due to the presence of small amounts of more readily available food material, either in the size used for weaving or in the natural non-cellulosic constituents of the raw fibres. Many moulds do not attack cellulose at all and grow entirely at the expense of these impurities, while even those which can rapidly destroy cellulose do so only if supplied, in addition, with certain metallic salts. Figure 4 shows the remarkable efficiency of scouring. It is a photograph of two sheets of fabric-loaded bakelite, one made with loom-state fabric, the other with scoured fabric, after incubation for four weeks in a tropical atmosphere.

PAPER

In supplying an army, paper is used in very large quantities, for stationery, instruction books, packing, labelling, and as built-up containers for ammunition. Most common varieties of paper, when exposed to a humid atmosphere, lose most of their strength from the effects of moisture alone

before damage due to moulds is appreciable. Nevertheless it is often possible to dry out paper which is merely wet, but, if mould attack also is extensive, the damage is irreparable. Figure 6 shows an instruction book reduced to a mass of pulp by the combined effects of moulds and moisture.

A considerable amount of research during the war was therefore directed to the production of papers which would retain their strength when wet and to methods of mould-proofing them. Labels have been satisfactorily proofed by treatment with aqueous solutions of sodium pentachlorphenate, while wrapping papers have been treated with copper by the cuprammonium process or in the form of copper naphthenate. In the case of built-up containers the weak point is often the adhesive, but great improvements have been effected by using modern 'plastic' adhesives, such as urea-formaldehyde polymers, instead of the older types (figure 7).

LEATHER

The susceptibility of leather to attack by moulds depends chiefly on the method of tanning. Vegetable-tanned leather, as most people know only too well, rapidly becomes covered with mould under conditions of temperature and humidity far less severe than those obtaining in the tropics. Chrome-tanned leather, on the other hand, has been proved to be almost completely resistant, a fact which links up with the protective action of chromic oxide on fabrics. Semi-chrome leather, as would be expected, is intermediate in resistance. Unfortunately, chrome-tanned leather has physical properties which render it unsuitable for some purposes—boot soles, for example—and in any case the production possible during the war was insufficient to allow of more than a part of the leather equipment being made from this material.

Little is known at present about the effect of mould on leather, a problem now being investigated by the British Leather Manufacturers' Research Association. Certainly luxuriant growth can be cleaned off and the leather appears to be none the worse as regards strength and suppleness. Nevertheless, mouldy articles are unpleasant to handle and, particularly in the case of items of clothing, have to be cleaned frequently. With much equipment the damage is thus to be assessed in terms of the man-hours required for maintenance in good condition. Mould on instrument cases, particularly those for protecting optical equipment, can be more serious, as it may spread to the contents and, in addition, attracts mites. The majority of mechanical failures in leather equipment can be traced either to rotting of the leather owing to contact with iron or to breakdown of the stitching owing to attack by moulds. It is essential that all thread used in making up leather goods should be adequately mould-proofed, preferably by impregnation with chromic oxide.

A large number of experiments have been carried out to test the efficacy of various substances as protectives for vegetable-tanned leather, and to find the most suitable means of application of the selected antiseptics. Oil-soluble organic mercurials, which in other connections have proved to be the most potent of all anti-fungal agents, were first tested, but gave erratic and, on the whole, disappointing results. Undoubtedly the best of all the substances tested is *p*-nitrophenol, a very high degree of resistance being conferred by the addition of 0·3 per cent. of this compound (calculated on the weight of the leather). The antiseptic may be incorporated during manufacture of the leather, but in many cases it is preferably applied to the made-up articles in order to ensure protection of cut edges. It is used as a 1 per cent. solution in methylated spirit or a 50/50 mixture of spirit and water, and is sprayed or brushed on so as to add the correct amount. A somewhat less effective method of application is to treat the articles with dubbin containing 1 per cent. of the antiseptic. Often, of course, this was the only practicable method of treating equipment which was already in commission before treatment by manufacturers became general. Another antiseptic, recommended for use when supplies of *p*-nitrophenol are unavailable, is β-naphthol. It is applied in the same way as *p*-nitrophenol, but is of lower efficiency.

OPTICAL EQUIPMENT

The most interesting, and perhaps the most difficult, of all the problems investigated concerned the occurrence of mould in optical instruments. The problem is a very old one, and a certain amount of rather spasmodic research was carried out before the war, but in peacetime the servicing of damaged instruments is comparatively easy, and the total number in use is only a fraction of those needed in war.

Glass apparently contains nothing on which moulds can feed, certainly neither of the essential elements carbon and nitrogen, yet optical instruments such as binoculars, telescopes, microscopes, range-finders, and gunsights often become unusable after a few months in the tropics. Undoubtedly mould most frequently originates on

organic matter, dead or alive, which finds its way into imperfectly sealed instruments. The live culprits are mites, which abound in tropical forests, and they gain entry by eating their way through lutings or by creeping along badly fitting screw threads. They carry fungus spores on their hairy bodies, and as they often die in their hiding-place from lack of food, they serve as a source of nutriment for the moulds. In many cases, however, mould growth occurs on glass surfaces on which neither dust nor mites can be detected. The amount of growth is then comparatively slight, usually consisting of a network of fine filaments without any sporing structures. It is nevertheless sufficient to spoil definition, or, if it occurs on a graticule, to interfere seriously with the field of view. Figure 3 shows a fairly typical case of mould on a clean glass prism, the dark spots being knots of mycelium and not dust particles.

Often the growth is entirely superficial and can readily be cleaned off, but sometimes the glass is definitely etched, and has to be resurfaced to restore normal transmission. Even when no etching occurs, stripping, cleaning, and reassembly are jobs for the expert and cannot easily be carried out without a proper workshop.

Instruments of the fixed-focus type are comparatively easy to protect. If accurately made and assembled in a dry atmosphere they cannot develop mould unless the sealing breaks down. On the other hand, all instruments of the focusing type breathe to a certain extent, owing to the pumping action of the focusing adjustment, moist air being drawn in and gradually raising the relative humidity of the contained air to that of the atmosphere outside. It is extremely difficult to ensure that no mould spores enter an instrument during manufacture, and if any are present they will germinate as soon as the relative humidity reaches the critical point (about 75 per cent. for the species most commonly found). In addition, lutings used to seal lenses in cells and cover plates on the bodies of instruments are liable to dry out and crack in dry weather, and then, when humid conditions return, admit not only moisture but mould spores as well. It is probable that the only entirely satisfactory solution of the problem will result from complete redesign of most items of optical equipment, so as to ensure complete sealing even when focusing has to be allowed for. During the war, however, it was necessary to find means of prolonging the useful life of thousands of instruments in use and in process of manufacture.

The first essential was to ensure that all parts of instruments other than the actual optical systems were rendered mould-proof. Lutings, greases, paints, and lacquers were reformulated so that they should contain no ingredients capable of providing nutriment for moulds; this involved testing very many samples in the efforts to combine immunity with all the desired physical properties. Finally, a large number of experiments were carried out in order to find the best means of protecting the glass.

One method which has been extensively investigated is the fitting of instruments with small capsules containing a volatile antiseptic. The capsules, made to screw in from the outside to permit of easy replacement, are provided with diaphragms of sintered glass, through which the vapour can diffuse without any danger of solid particles being dislodged. The method, though attractive in theory, is limited in practice by the difficulty of finding the ideal antiseptic. It must be volatile but not too readily volatile. The vapour must have no action on any of the metals used in the construction of optical instruments, nor must it affect optical cements or lutings. So far, the most promising materials found are *m*-cresol acetate (first used in America and called 'cresatin') and thymol, but neither is entirely free from disadvantages.

Another means of protection which has been tested is the insertion into instruments of capsules containing silica gel, designed to keep the relative humidity of the enclosed air below the point at which moulds can grow. Trials carried out in this country have shown that very small quantities of the desiccant, such as can readily be inserted without interfering with the transmission of light, are effective for several months, even when sealing is far from perfect (figure 5).

There have not been, as yet, sufficient field trials to determine which of the two methods will give the better protection under service conditions, although there is reason to believe that, with improvements in the technique of sealing instruments, it will be possible to give reasonably lasting protection by means of desiccants. They have one great advantage over volatile antiseptics in that they also eliminate trouble due to fogging of lenses by condensed water, but it is possible that a combination of both methods will be found to be better than either alone. In any event a really satisfactory solution of the problem is in sight. This programme of research, like many others designed to solve wartime problems, has led to the development of new methods of lasting value in peace.

Whales and whaling

L. HARRISON MATTHEWS

By their size alone whales have always arrested the attention of even the most indifferent, and by their peculiar structure and almost unknown ways of life they have long interested the zoologist. Their economic value, too, has not been overlooked by the world of commerce, and the excitement and danger of hunting them have appealed to the adventurous. On this fascinating subject Dr Matthews writes with the authority of one who has himself voyaged to the Antarctic and studied the life-histories and habits of whales at first hand.

Whales form a group apart from all the other mammals—for mammals they are, breathing air with lungs, having warm blood, bringing forth living young, and suckling them on milk. Their remote ancestors more than fifty million years ago were four-footed beasts living on the land, but the process of evolution throughout that immense period of time has left them with a fish-like form, fin-like fore limbs or paddles, and no external hind limbs—though rudiments of these are still to be found embedded in the tissues within the body. The tail is expanded into wide flukes, much like a fish's tail, except that it is horizontal and not vertical; it forms the chief means of propulsion. Some whales, too, have a fin on the back, resembling a fast motor-boat's skeg-keel, which helps in steering a straight course. In harmony with the aquatic habitat, the skin of whales is without the hairy covering usually found on mammals, except for a few scattered hairs on snout and chin (remains of the whiskers and beard) which show their affinities with their fully clothed relations. In compensation for the loss of hair, whales have underneath the skin a thick layer of blubber, a fatty tissue which serves to insulate the warm body from the cold water in which it floats. The aquatic habitat, too, has allowed the development of the great size of some whales. No animal of such size, whose body was not supported by floating in water, could exist; in fact, if a large uninjured whale becomes stranded and left by the tide, it is suffocated by its own weight, which crushes its chest and prevents it from breathing. But not all whales are of gigantic size, for the porpoises and dolphins, which are comparatively small, belong to the same tribe.

There are many different kinds of whales, but they fall naturally into two main groups, the toothed whales and the whalebone whales, the differences between which are closely connected with their food. The toothed whales, as their name implies, are provided with teeth for seizing their prey, which consists of fish and, probably even more important, cephalopods—squids and cuttles. The teeth, unlike those of most mammals, are all similar, being pointed and peg-like and not divided up into incisors, canines, and molars. In many whales, also, they are very much more numerous than in any other mammals, but in some there is a reduction in number; the great Sperm Whale, for instance, has teeth in the lower jaw only, and when the mouth is closed they fit into corresponding sockets in the gum of the upper jaw. In some of the smaller whales the teeth are reduced still further to a single pair, placed near the tip of the lower jaw.

The feeding mechanism of the whalebone whales is quite different. They do not catch individual animals for food, but filter the sea water to extract in bulk the vast numbers of small creatures which are collectively termed 'plankton.' Plankton consists of all the small plants and animals, many of microscopic size, which float in enormous numbers in the upper layers of the sea; their great abundance is shown by the fact that the largest whales feed on little else. The apparatus of the whalebone whales for filtering plankton out of the sea is peculiar. There are no teeth in the mouth, but hanging from the upper jaw is a series of many fibrous horny plates set crosswise on each side, where the upper teeth are placed in ordinary mammals. These horny plates are misnamed 'whalebone.' The inner sides of the plates are frayed out into separate fibres, so that a sort of hairy mat, supported by the plates, is formed on each side of the mouth. When the whale is feeding it takes in a mouthful of sea water together with its contained plankton, shuts the mouth, and raises the tongue so that the water is driven through the mat, between the plates of whalebone, and out through the lips at the side. The plankton thus left stranded on the mat of whalebone fibres is then swallowed.

When diving, the whalebone whales normally remain below for from five to fifteen minutes, and the toothed whales from thirty to sixty minutes, but all can greatly prolong their submergence if necessary. The deepest measured dive of a Fin Whale was over 350 metres, and there is some evidence of a Sperm Whale diving to 900 metres. When a man descends in a diving suit, air is pumped down to him at a pressure slightly greater than that produced by the column of water above him; the nitrogen in the air dissolves in his blood and tissues until, if he remains long enough under sufficient pressure, they are saturated. On ascending towards the surface the pressure decreases, and his blood and tissues are then super-saturated: the excess gas appears as bubbles which block the smaller blood-vessels and accumulate in the tissues, producing caisson sickness, or 'bends.' If the release of pressure is sufficiently great and quick, intense pain is produced and death may rapidly occur. When a diver has been for some time at considerable depths, his return to the surface must be gradual to allow the excess gas to be washed out of his tissues and prevent his becoming a living soda-water bottle. How is it, then, that whales can take sufficient air down to allow long-continued activity, and how are they able to avoid being killed by caisson sickness? The subject is not yet completely understood, but the latest work of the Whale Research Institute at Oslo has thrown much light on it. Several factors are concerned in prolonged diving. During diving the metabolic rate of the whale is reduced, so that the oxygen consumption of the body is greatly lessened—perhaps to only about 30 per cent. of the normal rate. The myoglobin of the muscles may contribute as much as one-third of the total oxygen store of the body, and the complex networks of blood-vessels—the *retia mirabilia*—act as an arterio-venous shunt so that the circulating blood by-passes the muscles during the dive. And, finally, the amount of oxygen removed from the air during breathing at the surface is unusually high. As for deep diving and caisson sickness, the whale takes down only the gases dissolved in its tissues and the air in its lungs, in contrast to the human diver who is supplied with a constant stream of air and is filling and emptying his lungs continually while below. The safety of the whale at great depths depends upon the lungs becoming so compressed that the air is driven out of the absorbing part of them. At a depth of 100 metres the compression of the whale's lungs is so great that the alveoli, where gaseous exchange takes place, are completely collapsed, and all the air is driven into the rigid tubes of the bronchi, trachea, and nasal passages, where the invasion rate of nitrogen is negligible. The whale can then return rapidly to the surface without danger of suffering from air embolism.

Even primitive man appreciated the value of whales, as is shown by the bones sometimes found in ancient kitchen-middens and hut sites; in fact, a stranded whale must have been a godsend to dwellers near the coast, a position curiously reversed nowadays when the responsibility for removing such a malodorous object devolves upon the owners of foreshore rights. At first, doubtless, the supply of meat provided by a whale was its chief attraction, but for many centuries the main value of whales has been the oil which can be extracted from them. When man had achieved the building of seaworthy boats, sooner or later he was sure to discover that fortuitous strandings could be improved upon by deliberately driving whales ashore. This primitive way of hunting still survives in the Faroe and Shetland Islands, where to this day schools of Pilot Whales —a rather small species not exceeding thirty feet in length—are annually driven ashore to the number of some hundreds and are there slaughtered, cut up, and boiled down for their oil. During the middle ages the Basques carried on a profitable fishery by putting to sea in small boats to hunt and capture the rather slow-moving and coast-frequenting Atlantic Right Whales, with such success that they practically exterminated them on their coasts. They did not drive the whales ashore, but evolved the technique of harpooning them with barbed spears attached to the boat by a line, and playing them until they were so exhausted that they could be approached and killed by stabbing with a lance. The dead whales were towed ashore for cutting up.

When the numbers of whales declined through over-fishing, these enterprising men fitted out ships to go further afield in search of their quarry. The base of operation was thus merely transferred from shore to ship, for the actual hunting was done as before in small boats lowered from the vessel. Before long, the Right Whales were so rare off the temperate coasts of Europe that lengthy voyages into high latitudes grew to be the regular practice. Here the whalers found a further reward for their boldness, for within the Arctic circle they discovered another sort of whale, the Greenland Right Whale, which yielded a greater quantity of oil than any other. Throughout

the seventeenth and eighteenth centuries a large fleet of whale ships—French, Dutch, English, and Scandinavian—was regularly engaged in whaling voyages to the north, some ships boiling out their oil ashore at such places as Spitsbergen, Jan Mayen, or Bear Island, but others merely casking the blubber after cutting it into small pieces, and bringing it back to be boiled out at home. After the early part of the nineteenth century, northern whaling steadily declined, for Greenland whales were becoming scarce, and towards the end it was only the high value of the whalebone which kept it going. The extinction of the crinoline, together with the substitution of steel busks for whalebone in corsets, dealt the final blow at the industry; so that since the opening years of the twentieth century sailing ships have no more gone hunting the Right Whales of the Arctic.

On the New England and Connecticut coasts of America a similar evolution of whaling took place during the eighteenth century, but it was directed not only towards the Right Whales of the Arctic but also to the Sperm Whales of temperate and tropical seas. During the first half of the nineteenth century a very large fleet of Yankee whalers sailed the seven seas; but the civil war and the development of the petroleum industry started the ruin of American whaling, and the first decade of the present century saw the end of it. During the second half of the nineteenth century whaling voyages got longer and longer, up to five years away from home, during which time there would be visits in pursuit of Right Whales to the Arctic and Antarctic regions of both the Atlantic and Pacific Oceans, as well as months of cruising after Sperm Whales in the tropics. It was on these long voyages that the Americans developed the practice, adopted by whalers of other nations, of boiling out the oil on board ship in tryworks built on deck. The tryworks were a series of cauldrons set in brickwork, and the fuel used was the oil-soaked fibrous scrap remaining after the oil had been boiled out of the blubber. In spite of the danger of boiling such inflammable material on the deck of a wooden ship while at sea, there was not an unduly high loss of ships from fire.

The whaling carried on by means of harpoons hurled from small boats lowered by sailing ships was confined to a few species of whales, mainly Right and Sperm Whales, because these are the only sorts which float when dead. Other and larger species were inaccessible to this kind of whaling, because they are so large and active that the danger of attacking them, and the difficulty of even approaching such swift-swimming animals, are too great. Further, when dead they sink and would drag down with them any boat rash enough to have 'got fast' to them. But the existence of great numbers of the larger kinds of whales, known collectively as Rorquals and individually as Blue, Fin, Humpback, and Sei Whales, all immune from attack by the whalers, attracted the attention of Svend Foyn, an inventive Norwegian, about 1860. Foyn, realizing that entirely new methods were required, produced a very large harpoon fired from a cannon mounted in the bow of a small steamer and attached by a stout rope. By using a steamer he got the speed required to approach the Rorquals, and the heavy harpoon with its thick whale line gave sufficient strength to hold them when struck. In addition he devised an explosive head for the harpoon, fused to explode a few seconds after it entered the whale, which was usually quickly crippled if not killed at once. When dead the whale sank, but was hauled to the surface by heaving in the line on a steam winch. On arrival there it was made buoyant by inflating it with air pumped in by means of a hose fastened to a pointed pipe plunged into the body cavity. The carcass could then be towed home to be cut up and boiled down at leisure. This method of whale-hunting is the basis of the modern whaling industry and is essentially that in use on a large scale at the present day. Foyn's methods of hunting were used in conjunction with shore stations—factories at the water's edge of a sheltered harbour—where the whales were hauled on land and the products extracted with the aid of machinery.

The exploitation of the hitherto untapped resources provided by the Rorquals led to the establishment of whaling stations, of which the management and practically all the skilled labour were Norwegian, in many parts of the world; while in the tropics the same methods were used for the pursuit of Sperm Whales. A prosperous industry became firmly established, though after some years a falling-away in the numbers of whales became obvious at some places.

At the end of the nineteenth century much attention was being turned towards the exploration of the Antarctic, the last remaining great unknown region of the world. In 1902–3 the Swedish South Polar Expedition's ship, the *Antarctic*, was under the command of the veteran whaler captain C. A. Larsen, who noted the abundance of whales in the Antarctic and the suitability of many of the islands of that region

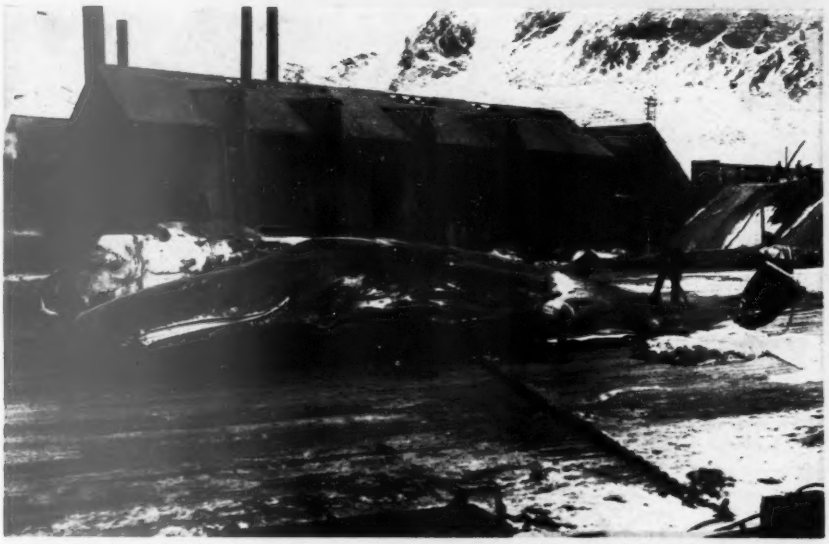


FIGURE 1 – *Ventral view of Sperm Whale on the flensing plane, showing factory buildings in the background.* (*Reproduced by courtesy of the Discovery Committee.*)

FIGURE 2 – *General view of Blue Whale, dorsal side uppermost.*
(*Reproduced by courtesy of the Discovery Committee.*)

FIGURE 3 – *A Fin Whale on the flensing plane at Grytoiken, S. Georgia.* (*Reproduced by courtesy of the Discovery Committee.*)

FIGURE 4 – *Southern Right Whale, showing fin and baleen.*
(Reproduced by courtesy of the Discovery Committee.)

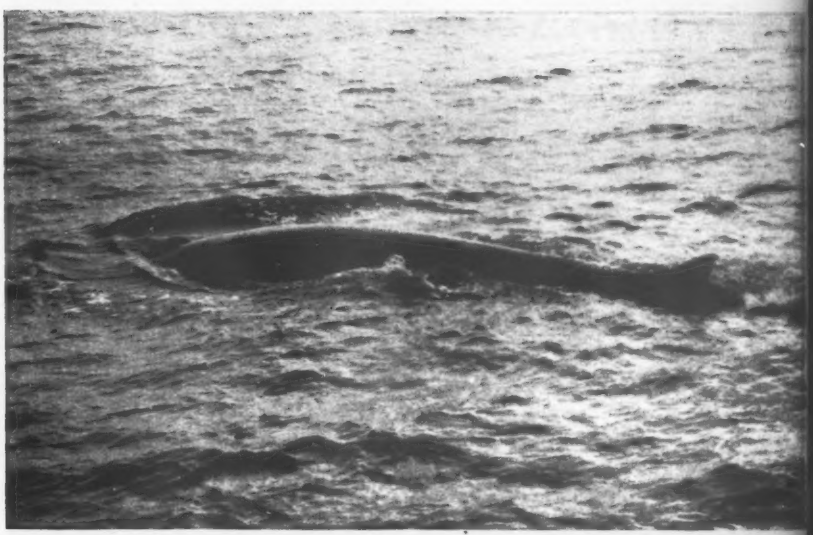


FIGURE 5 – *Whale breaking surface. Photograph taken from the* William Scoresby *during the season* 1934–5.
(Reproduced by courtesy of the Discovery Committee.)

FIGURE 6 – *A factory ship showing a Blue Whale being hauled up the slipway to the flensing deck.*
(Reproduced by courtesy of the Discovery Committee.)

for the establishment of whaling stations. After his rescue and return (for the ship was lost) he found financial backing in South America to organize a whaling expedition on modern lines. In 1904 he started the first Antarctic whaling station in a sheltered cove on the island of South Georgia. Whales were abundant and the enterprise was a great success, paying a dividend of 70 per cent. in its first year; for the invention of the hydrogenation process for converting oils to fats had created a great demand for animal oils in the margarine and soap trades. Then started a rush for the new El Dorado, and within a few years a number of whaling companies were working on this island, and on the South Orkney and South Shetland islands farther south. The nearest inhabited country to these regions is a British Crown Colony, the Falkland Islands; and though the Antarctic mainland and islands had always been more or less a no-man's-land to the sealers, who were the only people to have used them since their discovery, Captain Cook had formally taken possession of South Georgia in the name of the British Crown when he discovered the island in 1775. The new activities in the south soon came to the notice of governments, and in 1908 Letters Patent under the Great Seal extended the boundaries of the colony of the Falkland Islands to include a large sector of the Antarctic continent, and its surrounding islands, which now form the Dependencies of the Falkland Islands.

As a result of territorial jurisdiction the British Government was able to introduce regulations to govern the whaling industry, in order to prevent an over-exploitation of the whale population and the consequent ruin of an important world-supply of raw materials. The regulations provided, amongst other things, for the issue of licences to engage in whaling, and the leasing of land on which whaling stations were to be built. They limited the number of hunting steamers or catchers, required whale carcasses to be completely utilized without waste, prohibited the killing of whale calves or their dams, and defined a close season. The application of the regulations was not difficult, because whaling could be carried on only from shore stations or floating factories—large ships provided with the necessary machinery for rendering down the whale carcasses cut up in the water alongside—both of which needed the shelter of harbours within territorial waters. The revenue derived from licences, leases, and a royalty imposed on the oil produced, provided a fund which was to be used for promoting the interests of the industry. In the course of time this amounted to a very large sum, which has been expended according to intention.

Soon after the start of southern whaling, the Government and its advisers saw the danger of repeating the mistakes made in the past in other parts of the world—as for instance in the Arctic, where over-fishing had ruined a once prosperous whaling industry. An Inter-Departmental Committee on Research and Development in the Dependencies of the Falkland Islands reported in 1920 that a rational regulation of the whaling industry demanded a full knowledge of the life-histories and habits of whales, and all that this implies, and recommended that scientific investigations should be started without delay. A scientific expedition in Captain Scott's old ship, the *Discovery*, was accordingly dispatched in 1925, and from that date until the present day scientific research in all parts of the Antarctic has been carried on by the Discovery Investigations Committee, using first this ship and then her successor, the splendidly equipped research ship *Discovery II*, and her smaller consort the *William Scoresby*. The results achieved have been of the greatest value, both to science and to whaling.

Before the *Discovery* researches began it had been assumed that whales grew slowly and attained a considerable age in reaching their full size. Among the first facts to emerge was the surprising one that they reach maturity quite quickly, and their full size at a comparatively early age. Of the many thousands of whales examined by the expedition, only one was found whose age was estimated at about thirty years, and the vast majority were not older than five or six. The largest species of whale is the Blue Whale, which when fully grown may reach a length of nearly a hundred feet; it is about twenty-five feet in length at birth and grows up quickly, reaching a length of over seventy feet, and being ready to breed, in two years. The period of gestation is roughly twelve months, that of suckling about six, and a further period of about six months elapses before breeding occurs again. The female Blue Whale thus produces a calf once every two years. The majority of the calves are born about the southern midwinter, but not in the cold Antarctic seas, for the whales have regular migrations and move north to temperate waters during the winter, and the young are usually several months old before they accompany their mothers to the south. The Blue Whale and a rather smaller species, the Fin Whale, which reaches sexual maturity at a length of about sixty

feet and whose life-history is very similar, together make up the major part of the Antarctic catch; a third and smaller species, the Humpback, is of minor economic importance.

The southerly migration during the Antarctic spring and summer is entirely a feeding migration. The plankton of the south is very rich and is characterized by the presence of vast quantities of a crustacean much like a large shrimp—'Krill' or *Euphausia superba*—which there forms practically the whole diet not only of the whales but of many of the seals, penguins, and other members of the fauna. Whales quickly fatten on this food, and their blubber is conspicuously thicker and richer in oil soon after they reach the southern feeding grounds. The life-history of the helplessly drifting Krill is a complicated one. The eggs are laid near the bottom in deep water, 500–1,000 metres down, and the young when hatched drift in the current of comparatively warm water which flows south deep below the surface and wells up near the ice edge of the Antarctic continent. Here the adolescent Krill become concentrated and then drift north again in the cold Antarctic surface current, probably taking several years to become adult.

By about 1935, so much information had been accumulated about whales, their food, migrations, and the hydrological and meteorological factors governing their distribution, that it was evident that the whaling industry could with profit base its activities on this foundation of comparatively exact knowledge. But a new factor had now entered the problem of whaling, making the application of regulations to the industry as a whole impossible: this was the development of pelagic whaling. In 1925–30, when new whaling ventures could no longer obtain licences, the revolutionary move was made of fitting out a floating factory to operate entirely on the high seas, and to be completely independent of harbours. The many technical difficulties of such an undertaking were successfully overcome, and the advantages of being free from regulations, licences, and royalties, and of being able to cruise where whales were most abundant, were demonstrated. Once again the pioneering success was followed by many imitators, and there ensued an over-production of oil so great that the industry was forced to refrain from sending any expeditions south for a whole season, until the surplus was absorbed by the market.

The only remedy for this state of things was international agreement, and accordingly a conference of the interested nations met in London and drew up regulations for the industry. Each year the amount of oil to be produced is decided upon before the expeditions sail south, and the season during which, and the places where, whales are to be hunted are laid down. Hunting is thus confined to those regions where the whales are in best condition, and is prohibited in those where their exploitation is wasteful. It was hoped in this way to conserve the stock of whales so that an annual crop could be gathered safely, though a disquietingly high proportion of immature whales continued to be shown in the returns of the catches. All nations interested in whaling accepted the regulations except Japan; but Germany, though signing the agreement, did not observe it.

The modern pelagic whaler is a large ship of 20,000 tons or more, fitted with a ramp up which the dead whales may be hauled out of the water on to the flensing deck, where they are dismembered and the products extracted by the aid of elaborate machinery. She carries a crew of several hundred men and is completely self-reliant, having on board sufficient fuel for the factory and her attendant catchers as well as for steaming, and for distilling the large amount of fresh water required. Her chief homeward cargo is, of course, oil, which is used in the manufacture of margarine and soap, but, in addition, the whale meat and bones are used, after extraction of the oil, for producing feeding stuffs, guano, and bone flour. During the ten years before the late war the annual world catch has varied from 24,000 to 44,000 whales, producing from about 400,000 to over 540,000 tons of oil.

During the first season of the war the whaling fleet was in the Antarctic, but on their homeward voyages some of the ships were sunk and others were captured by the Germans, who managed to get at least one with her cargo safely into Bordeaux. Most of the remainder were thereafter used as oil fuel transports, and in that service many of them were lost. In the present season a diminished fleet is again at work, some of the ships being splendid new ones specially built for the purpose. The results of their hunting are awaited with interest, not only because of the universal famine of fats and other whaling products, but also for their biological importance. For the whales have enjoyed a close season of four to five years, and the effect of this on the numbers and individual sizes in the population will produce information not only of great scientific value but of fundamental importance to the whaling industry.

Book reviews

MOULDS AND INDUSTRY

An Introduction to Industrial Mycology, *by George Smith. Pp. xiv + 271. Edward Arnold & Company, London. Third edition,* 1946. 20*s. net.*

The clinical success of penicillin and other antibiotics, the increasing industrial importance of fermentation processes, and the problem of preserving equipment from the attacks of micro-organisms have led many who possess little or no biological training to undertake the growth of moulds and the study of their metabolism. Such workers, among whom chemists are perhaps the most numerous, have an urgent need for an introductory book on mycology which is essentially practical in its outlook and is intelligible to the non-botanical reader. Mr Smith's book—first published in 1938 and now in its third edition—admirably meets this need. It is clear, it skilfully anticipates those questions which the beginner is most likely to ask, and it is illustrated with more than one hundred and fifty photomicrographs of exceptional merit. The first half of the book consists of descriptions and illustrations of the most common genera of moulds, emphasis being laid on those of the greatest practical importance. The remaining chapters are devoted primarily to accounts of laboratory methods and of the industrial significance of moulds. Besides numerous literature-references in the text, the book contains a useful guide to standard books and journals on mycology.

BRITISH BUTTERFLIES

Butterflies, *by E. B. Ford. Pp. xiv + 368, with 48 coloured and 24 black-and-white plates. Wm. Collins Limited, London.* 1945. 16*s. net.*

This stimulating and scholarly book is not for the mere collector of 'abs.' and 'vars.,' but will help the real student to discover facts which may be of permanent value in increasing knowledge of species formation, even among such hackneyed subjects as British butterflies. Dr Ford takes for granted the usual formal descriptions, and uses the biology of the insects as a basis for the discussion of several fundamental themes. Three of the fourteen chapters form an introduction to the theory of genetics, a subject on which the author is a recognized leader; they have a practical use in showing the lines along which results of value may be obtained. Much attention is paid to variation, and the field naturalist will be particularly interested in the chapter on evolution with its suggestive accounts of natural selection at work. The origin of the British butterfly fauna is discussed in the last chapter. There is a unique series of colour photographs of each species (alive in its natural surroundings), which is utilized to show points by which classification is aided. There are many other fine coloured or black-and-white plates, and maps showing the precise distribution of thirty-two species.

G. D. HALE CARPENTER

WIRELESS RECEIVERS

Radio Receiver Design, Part II, *by K. R. Sturley. Pp. xv + 486. Chapman & Hall Limited, London.* 1945. 28*s. net.*

The first part of this book was reviewed in ENDEAVOUR three years ago [1943, 2, 162]. In this second part the author continues his detailed treatment of receiver design after the detector stage, but includes Automatic Gain Control and Automatic Frequency Correction as well as the general design features of audio amplifiers.

The reception of frequency-modulated signals is the subject of a separate section, in which a wide variety of demodulation circuits is well covered. All stages of television receiver design, from the aerial to the display, are dealt with in another section, in which the special characteristics required are given an authentic treatment.

Although the text is well supported by mathematics and calculations, these do not obtrude unduly into the explanations of physical principles. Altogether this book can be thoroughly recommended and fully bears out the promise of Part I. Each section is rounded off by a comprehensive bibliography.

S. JEFFERSON

NUCLEAR CYTOLOGY AND HEREDITY

Animal Cytology and Evolution, *by M. J. D. White. Pp. viii + 375. University Press, Cambridge.* 1945. 36*s. net.*

Dr White's book deals not with all aspects of animal cytology but exclusively with those which are most closely concerned in influencing the course of evolution, namely the constitution of the nucleus and, in particular, the organization of the chromosomes. There have, of course, been enormous advances in our knowledge of this subject since the appearance of the last great compendium on the subject, E. B. Wilson's *The Cell in Development and Heredity*. Many of these advances have been treated in Darlington's *Recent Advances in Cytology*, but even that work is already somewhat out of date, and it not only included botanical as well as zoological data, but was at least as much concerned with arguing the case for the author's theories as with a plain summary of knowledge. White's book therefore fills what has been something of a gap in the literature, and will be a most valuable work of reference for some years to come.

Dr White makes little attempt to develop any general theories of his own, and his book may therefore seem somewhat scrappy to readers not well acquainted with the field. Its merit is that it makes a practically complete survey of the data, and brings together in convenient form many of the rather out-of-the-way and peculiar phenomena which occur in certain groups. These examples enable Dr White to point out the weak places in some of the current theories, and his review is a great deal more than a mere catalogue, since his commentary contains many suggestions and criticisms of great interest and cogency.

C. H. WADDINGTON

CRYSTALLOGRAPHIC ANALYSIS

Chemical Crystallography, *by C. W. Bunn. Pp. xii + 422. Clarendon Press, Oxford.* 1945. 25*s. net.*

In the last few years crystallographic methods have been increasingly recognized as valuable aids in a variety of types of chemical investigation, but their wider use has been delayed by lack of general knowledge of the actual techniques and theoretical background required for their use.

Mr Bunn has set out to remedy this lack. He has written a very welcome—and a very readable—book designed to introduce the reader to the ideas and methods of crystallography as they can be employed in the study of chemical problems. The book covers a very wide field, from the examination of crystal morphology and refractive indices—most valuable in the routine recognition and identification of chemical substances—to the detailed X-ray analysis

of complex organic compounds by Fourier methods. There are chapters on X-ray powder methods, the measurement of unit cell dimensions, and the determination of atomic positions, all illustrated by a large number of excellent examples. There is also a description of one of the most recent advances in technique, namely the use of optical diffraction effects in structure analysis. The deviations in structure and texture of crystalline materials responsible for broadened X-ray reflections are also discussed.

As is necessitated by the broad scope of the book, the treatment of individual topics is not exhaustive. The serious student who wishes for more detailed information will nevertheless find very adequate guidance from the references quoted, and, as a whole, Mr Bunn's book should certainly encourage his readers to look farther into the subject. The illustrations are numerous and very well designed.

One misprint may give a little trouble. The formula on p. 158 should read:

$$\tan \delta = \frac{\cos \alpha^{X} - \cos \beta^{X} \cos \gamma^{X}}{\cos \beta^{X} \sin \gamma^{X}}$$

D. GROWFOOT

THE SEA AS AN ENVIRONMENT FOR LIFE

Recent Advances in the Chemistry and Biology of Sea Water, *by H. W. Harvey. Pp. viii + 164. University Press, Cambridge.* 1945. 10*s.* 6*d. net.*

In 1928 Dr Harvey rendered great service to all interested in the sea as an environment for life by the publication of his *Biological Chemistry and Physics of Sea Water*. He has now summarized the growth of knowledge since that date in this shorter, but no less valuable, book. The advances in this short period, from which the war years must largely be deducted, are very significant despite the small numbers of workers: a handful in this country, a few in the maritime countries of Europe, and rather more in the United States. It is noteworthy how very much of this work has been initiated at the Plymouth Laboratory of the Marine Biological Association by Dr Harvey himself and by Dr W. R. G. Atkins and Dr L. H. N. Cooper. It is sufficient to say of this book that it is written by a master of his subject; it is condensed and is essentially a work of reference, but in the last, and longest, chapter the reader will find the best available account of the factors underlying the general fertility of the sea, a topic which leads from the fundamental research of the chemist and physicist to the practical issues of productivity in terms of the supplies of fish for human consumption. C. M. YONGE

FLORA AND FAUNA OF LONDON

London's Natural History, *by R. S. R. Fitter. Pp. xii + 282, with 52 illustrations in colour. Wm. Collins, London.* 1945. 16*s. net.*

Mr Fitter has written a delightful book, full of out-of-the-way information. The area he covers is that within twenty miles of St Paul's; and in spite of the spread of houses, this is a very wide field for one whose theme includes all branches of natural history. Indeed, the spread of houses in some respects extends the field, as animals and plants introduced by man come within the author's scope. Inevitably, therefore, much has had to be left out. The fish, for example, get rather patchy treatment, and no mention is made of even such a curious sight as that of gulls catching small pope in the waterworks near Molesey and dropping them again, apparently unhurt, on the paths around.

The material is arranged by periods, the first six chapters covering those from pre-Roman times to the middle of the nineteenth century. Thereafter Mr Fitter is concerned with the modern period, in which he considers such topics as 'nature indoors' (lice, rats, etc.), the built-up areas (which offer such pleasant diversions as a discussion of the recent colonization by black redstarts), and the influence of trade, traffic, water supply, refuse disposal, farming, sport, and finally war. The last has resulted in a remarkable growth of plants upon bombed sites.

Altogether this is a very readable and useful book, in which Mr Fitter, who is primarily an ornithologist, shows an admirable grasp of natural history in general. The coloured photographs are not altogether satisfactory, the colour sometimes being far from natural, so that in many cases the monochrome illustrations are preferable. IOLO A. WILLIAMS

A MODERN AID TO NAVIGATION

The Gyroscope and its Applications, *edited by Martin Davidson. Pp.* 256. *Hutchinson's Scientific and Technical Publications, London.* 1946. *Price* 21*s.*

It is known to most people that the gyroscope is used as the basis of a compass which is not affected by the proximity of magnetic materials, and that it is used in stabilizing ships and aeroplanes. Dr Davidson has had the excellent idea of producing a book, written by himself and other specialists in the subject, in which theory and practice are both described. The editor provides as clear an account, illustrated by experiments, of the theory of gyroscopic motion and precession as can be expected without the use of spherical trigonometry and generalized dynamics.

The chapters which follow are of a more practical nature. The marine instruments — compasses, gyro-pilots, and stabilizers—are described by G. C. Saul, and the aeronautical ones—direction indicators, rate-of-turn indicators, gyro-verticals, and automatic pilots—by J. A. Wells and A. P. Glenny. In both sections there are drawings and photographs of the instruments. The writers seem to have overlooked few of the practical applications, and the book should be both comprehensible and of interest to any mechanically minded reader. J. H. AWBERY

CELLULOSE

An Introduction to the Chemistry of Cellulose, *by J. T. Marsh and F. C. Wood. Pp. xi + 525, with 145 figures, including 23 plates. Chapman and Hall Limited, London. Third edition,* 1945. 32*s. net.*

The industrial importance of cellulose chemistry and the extensive and scattered literature relating to it make a comprehensive and well-documented textbook essential both for the research worker and for all those concerned with production. Since the first appearance of this book in 1938 there have been many developments in this field, and in successive editions the authors have incorporated much new material, though without deviating greatly from the original format.

As in preceding editions, the authors reveal a remarkably wide grasp of their very complex subject and, equally important, express themselves in a lucid and readable way. The text is supplied with comprehensive references to original literature and is very fully illustrated with plates and diagrams. The result is a summary of modern knowledge which will be invaluable to all those, both specialists and others, whose interests lie in this important field.

Notes on contributors

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Was born in 1891 and was educated at Merchant Taylors' School and at King's College, Cambridge, of which he was elected a Fellow in 1914. After service with The Queen's Royal West Surrey Regiment during the war of 1914–18 he returned to Cambridge, first as Balfour Student (1919–23) and then as Reader in Experimental Zoology. Since 1937 he has been Professor of Zoology in the University of Cambridge. Besides numerous scientific papers he has published two books, *Ciliary Movement* and *Experimental Cytology*.

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Was born in 1897 and was educated at the Stationers' Company's School and the Imperial College of Science and Technology (Royal College of Science), London. In 1919 he was appointed to the staff of the Chemistry Department of Imperial College, and was latterly Assistant Professor and University Reader in Physical Chemistry. During this period his scientific interest lay in various aspects of chemical thermodynamics and electrochemistry; at the same time he has been strongly attracted to administrative work. He has served as Honorary Secretary of both the Chemical Society (1934-39) and the Society of Chemical Industry. In 1933 he became Honorary Secretary of the Royal College of Science Association, of which he is now President. During the war he was associated with various technical committees advising the Government. From 1940 to 1941 he was Acting Secretary of the Imperial College; at the end of 1944 he resigned his readership there to take up his present appointment as Secretary of the Royal Institute of Chemistry.

T. A. STEPHENSON,
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Was born in 1898. After eight years as Lecturer in Zoology at University College, London, he was in 1931 appointed Professor of Zoology in the University of Cape Town. In 1941 he took up his present post of Professor of Zoology in University College, Aberystwyth. He was in charge of the section of the Great Barrier Reef Expedition (1928–9), which studied shore ecology. This section worked on corals and the various invertebrates and seaweeds associated with them. During his tenancy of the chair at Cape Town he carried out, with the help of a dozen assistants, a biological survey of nearly two thousand miles of the South African coast between tidemarks; this was the most extensive piece of work of its type to be undertaken. He has published various papers on sea anemones, culminating in a two-volume monograph on the British species, published by the Ray Society in 1928 and 1935; a series of papers on coral biology in the Scientific Reports of the Barrier Reef Expedition, 1931–4; and another series, still continuing, on the results of the South African survey. His book *Seashore Life and Pattern* was published in 1944. He is interested in painting as well as in biology.

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Is Melville Wills Professor of Theoretical Physics in the University of Bristol. His scientific interests are primarily in problems relating to atomic physics, metals, and photographic emulsions. Besides various contributions to scientific journals he is the author of several books on physical subjects. These include *An Outline of Wave Mechanics*, *The Theory of Atomic Collisions* (with H. S. W. Massey), *The Theory of the Properties of Metals and Alloys* (with H. Jones), and *Electronic Processes in Ionic Crystals* (with R. W. Gurney). In 1941 he was awarded the Hughes Medal of the Royal Society. He was educated at Clifton College and at St. John's College, Cambridge. After graduation he was successively elected a lecturer at Manchester University (1929–30) and Fellow and Lecturer, Gonville and Caius College, Cambridge (1930–3).

GEORGE SMITH,
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Was born in 1895 and was educated at Accrington Grammar School and the University of Manchester, where he read chemistry. In 1919 he joined a firm of cotton manufacturers to establish a research laboratory, and in 1922 began to investigate the problem of mildew in Indian dhoties in conjunction with the then recently formed British Cotton Industry Research Association. This work directed his interest to mycology, on which he has since carried out much original research. At the end of 1930 he moved to the London School of Hygiene and Tropical Medicine, working with Professor H. Raistrick on the biochemistry of moulds and taking charge of the mycological side of the investigations. He was president of the British Mycological Society in 1945. He has published many papers and articles on textile subjects, the biochemistry of moulds, the taxonomy of moulds, and antibiotics; his book *An Introduction to Industrial Mycology* is now in its third edition. An enthusiast for music, he is also much interested in photomicrography, wood and metal work, and apple-growing.

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Was born in Bristol in 1901, and was educated at Bristol Grammar School and King's College, Cambridge, where he was an Exhibitioner. He spent four years with the *Discovery* expedition and has travelled widely in Europe, South America, and Africa, investigating the morphology and physiology of mammals. He is on the Councils of the Zoological Societies of London and Bristol and of the Marine Biological Association at Plymouth. He now holds a Research Fellowship at the University of Bristol. He is an accomplished and experienced field naturalist but has many other interests, including art.

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